MANAGEMENT OF HEIFER GROWTH IN DUAL-PURPOSE CATTLE SYSTEMS IN THE LOW HUASTECA REGION OF VERACRUZ, MEXICO

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ABSTRACT

The objectives of this study were to systematically evaluate the limitations of traditional management and the potentials of alternative practices in raising dual-purpose (DP) replacement heifers owned by farmers in the low Huasteca region, specifically in Tepetzintla, Veracruz, Mexico. The Cornell Net Carbohydrate and Protein System (CNCPS) model version 6.1 was the primary tool applied to specific management groups of heifers in a structured set of simulations. Sixty-nine simulations were conducted to evaluate the primary constraints (bottlenecks), and fifty-five additional simulations were utilized to evaluate probable outcomes from alternative management. Typical heifer management was determined from reports and observations of members of the Grupo Ganadero de Validación y Transferencia de Tecnología Tepetzintla (GGAVATT-Tepetzintla; a non-governmental farmer organization dedicated to cattle production), guided by inputs from a panel of Mexican professionals working in this region and by Animal Science professionals at Cornell University.

Heifer management groups, defined by three physiological stages of development (prepuberty, postpuberty and gestation) and their interaction with four forage seasons of birth (early rains, late rains, scarce rain, and low rain), were evaluated from weaning to calving. Findings revealed important understandings of the main biological and management constraints on DP heifer performance in tropical northern Veracruz. Animal performance was sensitive to season of the year, which reduced growth rate and delayed puberty, conception and, consequently, age at first calving (AFC).

Results using the CNCPS model accurately depicted typical growth in GGAVATT-Tepetzintla replacement heifers. Average CNCPS-predicted outcomes

based on chemical composition of feeds and feeding policies agreed with typical on-farm observations. This study clearly demonstrated the CNCPS to be a valuable tool for identifying nutritional constraints and for monitoring growth and development of heifers in the DP cattle system of northern Veracruz.

Analysis of typical management scenarios revealed important vulnerabilities in various physiological stages of development: deficits of metabolizable protein (MP) and metabolizable energy (ME) limited growth and delayed maturation. MP deficits resulting in body weights (BW) <200 kg at 10 mo of age were identified during the seven-month period after weaning. Negative ME balances begin to arrest growth performance after 10 mo of age, especially during the dry season (low rains) when feed quantity and quality are low. Regardless of their forage season of birth, most, if not all, heifers incur energy deficits during the final trimester of pregnancy. Negative ME dietary balance prior to calving reduces tissue reserves and thwarts growth. The low nutrient supply results in thin animals with growth that is chronically slow or arrested. Consequently, typically-managed heifers are frequently small and underweight for their age, which limits their feed intake capacity, subsequent milk production, and probable early postpartum return to ovarian cyclicity.

An alternative strategy was developed to alleviate dietary constraints (bottlenecks), using low cost, locally-produced feeds, especially forages (e.g., grass hay, sugar cane, legumes). This approach was aimed at feasibly assuring unarrested growth to achieve younger AFC with desired body weights and tissue reserves. The modest dietary inclusion of protein sources, like tree legumes, complemented by hay of good quality and sorghum grain, increased the MP available for growth in weaned animals, resulting in a BW of 210 kg by 10 mo of age. Dietary supplementation after ten months of age with sugar cane and legume during the most nutrient restrictive season (low rain) significantly improved the ME, increasing the average growth rates (from 0.29 to 0.41 kg/d) and forestalling BW losses from nutrient deprivation. More rapid growth in the seven months following weaning, and in the low rain season, resulted in average ages at puberty and conception of 15 and 21 mo, 3 and 8 months earlier than under typical management. Moreover, energy supplementation in the final month of gestation avoided the typical catabolism of tissue reserves, thus increasing adipose body tissue reserves.

The extra investment in providing good quality forages resulted in earlier ages at first calving and, consequently, in reduced total feeding costs of about $80 from fewer total rearing days (270 d) to first parturition. Heifers under alternative management calving at 30 mo of age had $81 to $117 greater discounted income above feed cost through first to third lactation than traditionally-managed heifers. Although the marginal rate of return (MRR) was negative (-1.41), inconsistent with usual interpretations, farmers might be expected to be most interested in technologies or management practices that both increase revenues and reduce costs, as in this case. Therefore, this expected outcome represents a clear economic incentive for farmers to reduce growth constraints by improving dietary management.

The GGAVATT-Tepetzintla farmers, and probably many other dual-purpose herd owners in northern Veracruz and other tropical regions of Mexico, undoubtedly have economic incentives to reduce AFC of replacement heifers. They also should benefit from increasing body weight and condition score at parturition by implementing nutritional strategies like those considered in this study. To achieve this goal, it is essential to know, and to accurately monitor, the quality of available forages and other feeds (i.e., determine chemical composition). Furthermore, effective management of properly differentiated groups of heifers that differ in their nutritional requirements requires competent use of a nutrition tool, such as the CNCPS model, to generate the needed management recommendations for farmers.

BIBIOGRAPHICAL SKETCH

Omar Cristóbal Carballo was born in Tepetzintla, Veracruz, Mexico on September 16, 1981. He grew up in a rural community of the municipality of Tepetzintla named Tierra Blanca, where he completed his elementary and junior high studies. He began his high school education in Cerro Azul, Veracruz, and finished this in Jalapa, the capital of the state. With incentive provided by the family business, dual-purpose farming, he decided to pursue undergraduate studies in veterinary medicine at the Universidad Veracruzana, Facultad de Medicina Veterinaria y Zootecnia in 1999. In 2004 he received his bachelors' degree in veterinary medicine and animal science.

He was accepted to pursue an MS degree in the Department of Animal Science at Cornell University in the fall of 2006. The Cornell University Department of Animal Science, the USAID-Mexico TIES project (Decision Support of Ruminant Livestock Systems in the Gulf Region of Mexico), and CONACYT (Consejo Nacional de Ciencia y Tecnología) supported his program of study.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 Introduction

Livestock production represents one of the main activities in Mexico's agricultural sector, comprising about 54% of the 200 million hectare national landscape (SAGARPA, 2004a; 2004b). The primary livestock products are meat (beef, pork and poultry), milk (dairy and goat), eggs, wool, leather and honey. In calendar year 2007 agriculture constituted approximately 30% of the gross domestic product (GDP)[1], an increase of about 1.4% from 2006 (INEGI, 2008). However, in the last two decades, the production of animal food products has grown less than domestic demand, which has dramatically increased importation (SAGARPA, 2004a; 2004b). Rapid population growth and greater urbanization coupled with increases in per capita incomes and market globalization have increased the per capita consumption of livestock food products in Mexico (Blake and Nicholson, 2004; Delgado et al., 1999; Salazar-Adams et al., 2006).

Cattle husbandry is one of the most widespread agricultural activities in Mexico. About 1.5 million producers derive incomes from cattle to support their households (Cobos-González, 2006). The national herd inventory, about 31 million animals in 2005 (SIAP, 2006a), is managed under various production systems: confinement, semi-confinement and dual-purpose (GAIN, 2007). The confinement and semi-confinement systems, found mostly in northern and central states, utilize considerable feed grains to produce approximately 70% of milk and one-third of the domestic supply of beef (GAIN, 2007; 2008). Yet, both systems face serious production problems due to low tariffs on imported beef and dairy products under NAFTA rules (GAIN, 2007; 2008), increases in international cereal prices (FAO, 2007; GAIN, 2007; 2008), and water scarcity in arid and semi-arid regions of the

[1] Agriculture's share was about 3.7% of the total GDP in Mexico in the calendar year 2007.

country (Magaña-Monforte et al., 2006; SAGARPA, 2004b). These factors have constrained production and increased the cost of intensive (high input) production systems.

The dual-purpose system[2] (DP) is located on about 25% of the national territory, especially in dry and wet tropical regions. It accounts for approximately 60% of the national herd inventory (SIAP, 2006) and produces 30% of the domestic supply of milk and two-thirds of domestic beef production. Cattle production from DP systems is cheaper and more profitable than that from intensive systems (Nicholson et al., 1994). However, outputs are far less than what might be expected given the number of animals and the amounts of resources (i.e., land, water, forage and cheap byproducts) utilized in this system (Magaña-Monforte et al., 2006). It has been pointed out that improving the management of DP herds may not only increase milk and beef production, but may also double their proportional contributions to domestic supplies, which would reduce foreign exchange requirements for these commodities (Absalon-Medina, 2008; Baba, 2007; Magaña-Monforte et al., 2006; Román-Ponce, 1981).

Husbandry information about DP cattle systems is relatively scarce. There are few records about production parameters as well as a lack of knowledge of cost and benefit for alternative technologies applied in the field (Magaña-Monforte et al., 2006; Román-Ponce, 1981). Land investment, pasture establishment and animals represent more than 80% of operating costs; management costs are limited to manual labor, maintenance of paddocks and other managerial inputs. Machinery and construction are minimal and rustic. Paddocks generally do not have stocking rates matched with plant growth and most go unfertilized (Román-Ponce, 1981).

[2] The dual-purpose system is commonly found in southern (tropical) Mexico, where animals feed on cultivated pastures or native grasses (Magaña-Monforte et al., 2006). Producers in these systems respond to prices in both the milk and beef markets (Nicholson et al., 1994).

Most DP farms have crossbred animals (*Bos taurus* × *Bos indicus* breeds) of unknown ancestry, commonly managed under extensive grazing (Román-Ponce, 1981). Animal feeding is based on seasonal pastures, occasionally supplemented with minerals (mostly common salt). Feeding management is one of the main constraints affecting cattle performance in the tropics due to the variation in quality and quantity of native forages during the year (Juárez-Lagunes et al., 2002a). Most farmers in the tropics do not practice forage conservation (e.g., haymaking or ensiling) or provide supplementation (e.g., commercial concentrate) during critical seasons of the year (i.e., dry season). Thus, the variability of forages throughout the year, mainly during the dry season, produces serious fluctuations in herd productivity (Villa-Godoy et al., unpublished).

Production parameter values from DP herds in the Mexican tropics are generally low (Appendix, 1). Moreover, a high proportion (33%) of replacement females has been reported relative to the productive herd (29% cows). The rate of replacement in DP herds is about 14%. This low rate has been associated with slow growth because only 14% of potential replacements possess the age and body weight sufficient for entry into the production herd (Appendix 2) (Román-Ponce, 1981).

Nutritional management of replacement heifers until calving influences the growth and development of the cattle herd (Cady and Smith, 1996). In DP systems, the age at first calving (AFC) is seriously constrained by the large amount of time required for replacement heifers to achieve adequate BW for mating. In tropical Mexico, reports indicate that animals reach puberty at more than 17 mo of age (Castañeda, 2003; Román-Ponce, 1981). Furthermore, Castañeda (2003) pointed out that the average age and weight at first calving in DP heifers is over 36 mo and weighing about 410 kg. These low parameter values have been related to the feeding programs in DP systems, which influence the average daily gain (ADG) and, consequently, the corresponding time for each physiological stage of development (González-Stagnaro et al., 2007; Villa-Godoy et al., unpublished).

Low milk yields and short-duration lactations in DP cows due to inappropriate body reserves are common in tropical settings (Absalon-Medina, 2008). Primiparous heifers frequently sustain lactations less than 200 days from insufficient body tissue reserves at calving (Deresz et al., 1987 cited by Villa-Godoy, unpublished). Furthermore, a negative energy balance contributes to a delays in reinitiated ovarian cyclicity, which incurs extended calving intervals (Absalon-Medina, 2008; Baba, 2007).

Heifer rearing is often one of the least well managed production stages in DP herds. Mismanagement during this stage could be attributed to a lack of information by DP farmers about the importance of this period of development on future animal performance. Generally, farmers reserve the best forages for the production herd, leaving the poorest for non-lactating animals (heifers and dry cows). Consequent, delays in heifer growth beyond a desired age at calving could be translated not only into production losses, but also into increased farm operating costs (James and Collins, 1992; Cady and Smith, 1996). These expenses generally go unperceived and unacknowledged by farmers who would need to derive them from records of inputs and resulting animal performance. Although reasons for delays in calving are many, poor nutrition is a major factor.

1.1 Target state and client group

Veracruz State, located along the Gulf of Mexico and characterized for its tropical climate, is a premier cattle producer in the country. Cattle occupy 43% of the

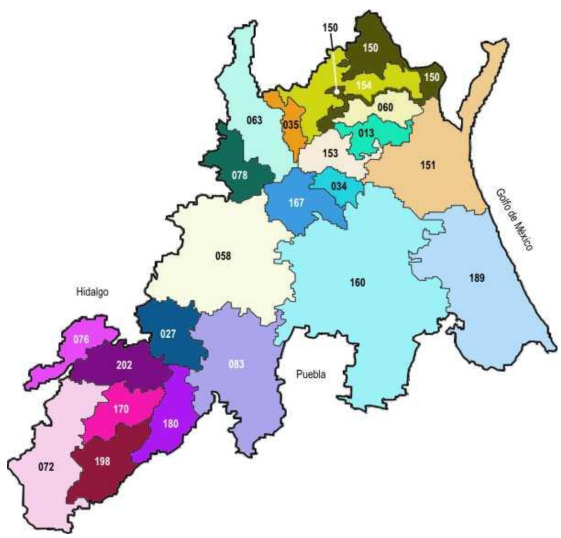
State territory (Herrera-Beltrán, 2006), and produce about 14% of the beef and 7% of the milk in Mexico. Thus, Veracruz is the first and fifth largest producer of these commodities (SIAP, 2008). Although there are about 60 thousand cows in specialized dairy herds in Mexico, most milk is produced by about 4 million DP cows, whose bull calves are destined for the beef market (SIAP, 2006).

Veracruz is divided into many counties and municipalities (Figure 1a). Northern Veracruz, or the Huasteca Veracruzana (high and low Huasteca), possesses about 1.9 million hectares devoted to about 1.2 million cattle, mostly in DP herds (OEIDRUS-Veracruz, 2003). The low Huasteca (Figure 1b), comprising 23 municipalities, is known for its DP cattle ranches and active farmer organizations, collectively known as Grupos Ganaderos de Validación y Transferencia de Tecnología (GGAVATT)[3].

The Instituto Nacional de Investigaciones Agrícolas y Pecuarias (INIFAP)[4] developed the GGAVATT methodology with farmer collaborators. The objective of this methodology is to evaluate technologies that increase herd and farm productivity and profitability, thus improving the welfare of member families (Román-Ponce et al., 2001). Through this mechanism, researchers and producers collaborate to identify and adapt technology options for farm implementation and widespread use (Román-Ponce et al., 2001). These technologies are diffused and adopted not only within a membership but also among GGAVATT organizations and other producers from the region. The implementation of technology schemes has allowed GGAVATT members to be more competitive, an outcome that is widely acknowledged among Mexican farmers (Aguilar-Barradas et al., 2005).

[3] Cattlemen's Testing and Technology Transfer Groups
[4] Mexican sister institution to the USDA's Agricultural Research Service.

Panel (a) http://portal.veracruz-llave.gob.mx:8025/municipales.html



Panel (b) http://www.e-local.gob.mx/work/templates/enciclo/veracruz/regiones.htm#reg02

Figure 1. Map of the ten counties of the state in Veracruz (a) and 23 municipalities forming the low Huasteca region (b).

The municipality of Tepetzintla, where the first GGAVATT was organized, is located in the low Huasteca region. Its main economic activity is agriculture (i.e., maize, beans and citrus), with more than 2400 production units. Livestock[5] activities comprise about 1067 production units on about 15,682 ha. Cattle production is one of the most important activities with more than 24,000 DP bovines (INAFED, 2005).

Tepetzintla, characterized by a warm-humid tropical climate (Am (f) Köppen classification), has two well-defined annual seasons: dry (November 1 to May 31) and wet (June 1 to October 31) (Figure 5). Seasonal variation in rainfall results in large fluctuations in the quality and quantity of feed supplies, which was illustrated by Absalon-Medina (2008) who studied DP cattle systems in the Central coastal (leeward) region of Veracruz. Markedly low or reduced nutrient intake by animals during the dry season resulted in low productivity and depressed reproductive performance of cows (Absalon-Medina, 2008).

GGAVATT-Tepetzintla has 12 member families with individual land holdings ranging from 22 to 148 ha that are stocked with about 0.8 animal units (AU) per hectare (1 AU equals 450 kg of animal live weight) (González-Ortega et al., 2007). Cattle reared on these farms are mostly crossbred animals whose genotypes are crosses between *Bos taurus* (Brown Swiss, Holstein Friesian and Simmental) and *Bos indicus* (Brahman) breeds (Appendix 3). The predominant breed group is the Brown Swiss × Brahman crossbred. These DP herds graze unfertilized pastures and receive commercial supplements during the first ten months of life, one month before calving, and during lactation. Heifers from 10 mo of age until the final month of gestation graze with dry cows and receive only mineral supplementation. This management

[5] Husbandry of cattle, pork, sheep, horses and chicken

results in age at first calving (AFC) of about 37 mo with an approximate BW at parturition of 450 kg (GGAVATT Tepetzintla, personal communication).

The development of a management system that achieves established targets or goals from birth through first lactation could more fully exploit animal potential for growth, reproduction and subsequent lifetime production (milk and calves). Management to achieve a younger average age at first calving requires a systematic undertaking throughout juvenile stages of growth and with evaluations of dietary options. Moreover, age at first calving, an outcome of rearing management, is a function of the ages at which breeding weight and conception are achieved. Consequently, reducing the time interval from birth to first calving would be expected to reduce the average total cost of dietary maintenance for replacement animals. Systematic evaluation of productivity limitations and potentials should provide information to managers of DP cattle systems in the tropics to more effectively manage their livestock and forage resources.

2.0. Review of literature

Heifer rearing is an essential component of the cattle enterprise. In US dairy farms rearing represents about 15 to 20% of total operating costs (Van Amburgh and Tikofsky, 2001). Estimates for the Mexican tropics are unavailable. Cattle producers from tropical regions typically pay little attention to this component of herd management, focusing more on milk sales and calf production. Replacement heifers may also receive lower priority because they have small immediate effect on herd income. Mismanagement of heifers, however, results in subsequent economic losses from delayed breeding and reduced first lactation milk yield (James and Collins, 1992). Reports from several Latin American countries indicate that older animals (>36 mo) at first calving with small frame size (low body weight) produce fewer calves and less lifetime milk than counterparts that are younger and with a larger body size (Ugarte, 1989; Urbina, 1991; Ventura and Barrios, 2002).

To evaluate the importance of heifer rearing options, this chapter briefly reviews assessments of heifer productivity limitations and potentials in DP herds in the low Huasteca region of Veracruz. Although most information was obtained from Latin American and temperate countries, emphasis is on information from tropical Mexico. The section first describes the growth and development of replacement heifers through different physiological stages of maturity. Then emphasis is placed on tropical forage characteristics and nutritional constraints commonly observed in heifers reared in the tropics. A review of the main forage alternatives found in the low Huasteca region of Veracruz is presented as a potential feedstuff resource to increase animals' growth. Important assessments using the Cornell Net Carbohydrate and Protein System (CNCPS) (Fox et al., 2004; Tylutki et al., 2008) in tropical scenarios are reviewed to identify the potentials of this model to predict and to manage animal production. Finally, a brief discussion of the economic importance of the age and body weight at calving of heifers on farm income is analyzed in the final section of this chapter. The aim of this review is to conceptualize in a systematic framework important physiological stages of development throughout the rearing period of heifers differentiated by forage season of birth and their growth trajectory through forage seasons of the year. These factors help to define management groups of heifers subjected to nutritional management using the CNCPS or similar models.

2.1. Heifer growth

Growth of an organism is defined as an increase in its mass. Tissue growth comprises cell multiplication (hyperplasia) and cell enlargement (hypertrophy) (Berg and Butterfield, 1976; Owens et al., 1993). Figure 1 represents total animal growth, which can be represented by plotting the body weight of the animal versus its age.

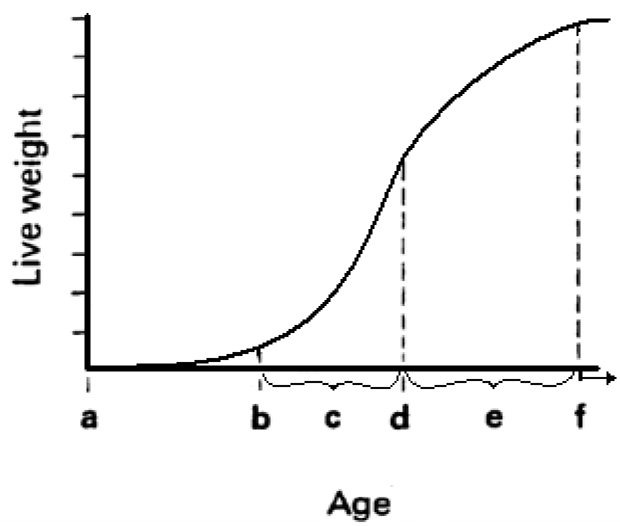


Figure 2. Growth curve of lambs showing a characteristic sigmoid response. Points represent a) conception, b) birth, c) self-accelerating phase, d) inflection point often associated with puberty, e) self-retarding phase, and f) maturity. Modified from Owens et al. (1993).

Normally, the pattern of growth is a traditional sigmoid curve (S-shaped; Figure 2). This response function has an initial exponential growth phase (self-accelerating or prepubertal phase) when growth is rapid; the average slope of the postnatal growth response is greatest until puberty (Berg and Butterfield, 1976; Owens et al., 1993). Prepubertal growth (c) is characterized by rapid deposition of bone and muscle (Berg and Butterfield, 1976; Owens et al., 1993; Thonney, 2005). This phase ends when tissue accretion diminishes and growth continues at a decreasing rate at, or near, puberty (d). The postpubertal (self-inhibiting) phase, from puberty to maturity (e) is characterized by inhibition in the growth of muscle and bone. Reduction in lean tissue growth, which has not been well defined, has been attributed either to a limitation in resources (space, nutrient supply, growth factors) or to an accumulation of products or inhibitory factor(s) that restrict cell division (Owens et al., 1993). During this development stage, the lean tissue accretion rate decreases and deposition of adipose tissue accelerates as the animal approaches its mature frame size. Finally, the rate of growth reaches a plateau at maturity (f), when increases in body weight (lean tissue) essentially cease. Mature body size is generally considered the point at which the maxima in bone and muscle tissues are achieved (Berg and Butterfield, 1976; Owens et al., 1993).

2.1.1. Heifer growth in the tropics

A few reports provide sketchy information about cattle growth performance in tropical Latin America, including crossbred replacement heifers. Posadas-Manzano (2005) cited several studies from tropical Mexico that classified weaning weights in DP herds (mostly crosses between Zebu and Holstein or Brown Swiss breeds) under three rearing systems. The first is traditional calf rearing, where cows are milked by hand once daily (generally in the mornings), after which the calf is permitted to suckle a whole quarter plus residual milk. The calves leave with their dams to graze in the morning, and then are separated and enclosed in the afternoon (~13:00 h) until the next day with little access to water and feed. Calves are raised in this manner until they are weaned. The growth rates from birth to weaning vary considerably. Rodrigez-Chessani and Sordo (1995) identified patterns of growth at four, seven and ten months of age with average daily gains in BW of 0.49±0.15, 0.36±0.10 and 0.40±0.08 kg, respectively. Body weights at weaning varied considerably, but the mean reported for this system was about 155 kg at 10 mo of age (González-Padilla, 1993; McDowell, 1996; Pérez-Hernández, 1992).

The second method of calf rearing is restricted suckling. In this system, calves are allowed to suckle a whole quarter and residual milk in the udder during the first four months of life. Calves are with their dams only at milking time. After milking, they are enclosed and supplemented daily with about 1 kg of commercial concentrate. Corresponding average daily gains are about 0.6 to 0.8 kg, which resulted in weaning weights of about 110 to 135 kg at four months of age (Posadas-Manzano, 2005). In a study in Central Veracruz, Pérez-Hernández et al. (2006) reported lighter weights at weaning (4 mo) for calves grazing *Cynodon nlemfuensis* without supplementation. Average daily gains from birth to weaning were 0.55±0.05 kg, which resulted in BW about 100±5 kg.

The third system, artificial rearing, consists of separating the calf from its dam on the third day of life followed by bottle-feeding of milk or milk replacer plus commercial concentrate (starter). These animals are weaned at about three months of age and weigh approximately 95 kg (Posadas-Manzano, 2005). Gleaves-Olvera et al. (1987) reported similar weights and ages at weaning of Brown Swiss calves reared artificially at the INIFAP research station, Las Margaritas, Puebla, Mexico. The animals obtained daily weight gains of 0.5 to 0.6 kg from birth to weaning. After weaning and until approximately 10 mo of age, heifers reared in this system generally received 1 kg to 2 kg of commercial concentrate and achieved BW of 210 kg with growth rates of ~0.5 kg/d.

Generally, the pre-weaning period is one of the most well managed stages within a DP herd, since this period requires more attention by farmers to control calf mortality. However, in most Mexican DP herds calves are mainly allowed to nurse residual milk (traditional calf rearing), and generally fed restricted amounts of low quality forages, rarely supplemented with concentrates. As a result of these management practices, DP heifers not often weigh about 200 kg at weaning (~9 mo of age), which delays reproductive events (e.g., puberty) and compromises future performance of cows and the herd (Romero Andrade, 2005; Van Amburgh et al., 2008).

The husbandry of replacement heifers is one of the weakest components in tropical herd management. This constitutes an input mismatch with the high genetic potentials for growth and milk production from crossbred animals with *Bos taurus* (Holstein, Brown Swiss and Simmental) and *Bos indicus* inheritance (Villa-Godoy et al., unpublished; Blake, 2008). These crossbred animals have been reported to have better growth rates and younger ages at puberty than straightbreds (*Bos taurus* or *Bos indicus*) in tropical settings (Grajales et al., 2006). The genetic potential of these animals is almost certainly being underutilized (Magaña-Monforte et al., 2006; Urbina, 1991; Blake, 2008). Generally, one of the stages most affected is the post-weaning growth period (Osorio-Arce and Segura-Correa, 2008). Post-weaning heifers generally experience slow, irregular growth, which limits lifetime performance (Maquívar and Galiana, 2006; Urbina, 1991). These variations in growth performance are translated into a variety of relationships between age (young or old) and the weight (light or heavy) at first calving (Wattiaux, 1996); in the tropics, it is most common to observe low body weights with advanced ages at first calving.

The age at puberty affects the onset of reproductive management and influences subsequent herd productivity (Maquívar and Galiana, 2006). The age at which this physiological threshold is achieved varies with growth rate and body development in relation to the animals' mature BW (Grajales et al., 2006; Short and Bellows, 1971). Heifers in DP systems in the Mexican tropics typically reach puberty on average at about 17 mo of age, but may vary from 12 to more than 21 mo (Anta, 1987 cited by Córdova-Izquierdo and Pérez-Gutiérrez, 2002). Variations in age at puberty are attributed to the animal's frame size, growth rate and genotype (Grajales et al., 2006). Generally, *Bos taurus* heifers reach puberty at younger ages and lighter weights than *Bos indicus* animals (Calderón-Robles et al., 1996; Maquívar and Galiana, 2006) with intermediate values for crossbred animals (Grajales et al., 2006; Maquívar and Galiana, 2006; Rosete et al., 1991; Villa-Godoy and Arreguín, 1993).

Once puberty is achieved, reproductive management does not immediately begin. Oftentimes breeding is delayed because of the slow growth during their pre- and postpubertal stages of development. Heifers in much of tropical Latin America are frequently bred when they achieve about 70% to 75% of their mature BW (González-Stagnaro, 1995). The amount of time required for DP animals to reach the proportion of their mature BW required for mating was clearly identified in a study in the state of Zulia, Venezuela (González-Stagnaro et al., 2007). In this study, 19,533 records from 47 commercial herds with crossbreds were analyzed to determine factors affecting age at first mating. Factors were management systems (improved or traditional), geographic zones (amount of rainfall), predominant breed genotypes (Holstein, Brown Swiss, Brahman and Carora), and critical control points such as weights at birth, weaning and mating. The results showed that age at breeding, which averaged about 31.5 mo, was earlier in high-input herds than in traditional ones (28.1 mo *vs.* 32.7 mo; $P<0.001$). Furthermore, first mating was at older ages for heifers reared in dry locations than in those with more rainfall (27.6 *vs*. 36.7 mo; $P<0.001$). Oldest ages at breeding occurred among heifers born (32.1 mo) and weaned (30.6 mo) during the dry season and bred during the rainy season (32.4 mo; $P<0.001$). These observations demonstrate the seasonal effect of forage quality and availability on subsequent animal performance.

Data from tropical Latin America indicate that productive and reproductive parameters differ greatly from those reported for heifers reared in temperate settings. Dual-purpose heifers reared in the Mexican tropics typically calve at more than 36 mo of age and weighing less than 450 kg of BW (mature BW 550 kg) (Castañeda, 2003; Román-Ponce, 1981; Villa-Godoy et al., unpublished). In temperate dairy systems average AFC is about 25 mo (USDA, 2007) at a BW of about 550 kg (mature BW 650 kg). Table 1 summarizes the average BW, ages and daily liveweight gains at breeding and calving from several reports of crossbred heifers (*Bos taurus* × *Bos indicus*) raised in DP systems in tropical Latin America.

Table 1. Body weights of animals with two frame sizes (small and large) at various stages of development in dual-purpose cattle systems in Latin America (Mexico, Colombia, Costa Rica and Venezuela) (Anta, 1987; Castañeda, 2003; González-Stagnaro et al., 2007; Maquívar and Galiana, 2006; Román-Ponce, 1981; Urbina, 1991).

Frame Size	Birth weight (kg)	Breeding BW (kg)	Breeding Age (mo)	Calving BW (kg)	Calving Age (mo)	ADG[1] (kg/d)	MBW[2] (kg)
Small	<32	320	27-32	360	36-42	<0.450	450
Large	~35	400	27-32	450	36-42	<0.450	550

[1] Average daily gain
[2] Mature body weight

Generally, animals that have been well managed during prepubertal and postpubertal stages are mated at younger ages because of the higher growth rates that these animals experience. These heifers are younger and heavier at calving. In the region of Puebla, Mexico (INIFAP research station “Las Margaritas”) studies of pre- and postpubertal supplementation were made with Brown Swiss heifers (Calderón-Robles et al., 1987). These animals were grazed in paddocks of African star grass and received 2 kg of concentrate supplementation (16.6% CP and 72% TDN). Ages and weights at mating were 18 mo and 350 kg, respectively. Calving was achieved at 29 mo with 440 kg BW (BW not specified if pre- or postcalving). Similar studies were carried out in a Venezuelan herd of 222 Brown Swiss heifers (Padrón and Vaccaro, 1987) fed chopped elephant grass (*Pennisetum purpureum*, 8% CP) and supplemented with 2 and 3 kg of commercial concentrate (20% and 18% CP, respectively). Heifers became pregnant at 16 mo of age with an average weight of 325 kg and calved at 28 mo of age with an average calving weight of 500 kg (not specified if pre- or postcalving).

Undoubtedly, there are several nutritional management constraints in DP rearing systems that variously affect the physiological stages of heifer growth and development until calving. If total feed intake can be increased (especially during periods of low rainfall), or if the nutrient content of the diet can be improved, more rapid growth can be expected. Improved dietary management would be expected to reduce AFC (less than 37 mo) and potentially increase BW (more than 440 kg) at calving in tropical production systems.

2.1.2. Chemical composition of growth

To understand the growth process, it is important to understand how body tissue chemical composition changes with tissue accretion throughout different life stages until maturity. Animal body composition is described by proportions of muscle, fat, and bone in the carcass or by the proportions of chemically measured amounts of water, protein, lipid, and ash in the whole body (Berg and Butterfield, 1976; Thonney, 2004). Dissection studies in cattle and sheep have shown little variation in muscle distribution among breeds of widely varying shapes (Thonney, 2004). Therefore, because BW in relation to mature weight is the principal determinant of composition at a given stage of growth, mature size is an indicator trait to approximate body chemical composition at different physiological stages of life (puberty, breeding, AFC).

Thonney (2004) reminded that there is wide variation among breeds within species in body composition at a specific weight, which is mostly due to differences in mature body weight. Generally, carcasses of animals of different mature-size contain about 50% muscle, 35% fat, and 15% bone, despite variations in mature weight. This is shown in Figure 3 for two animal groups of different mature size. These animals have the same composition at mature size, but the mature carcass of a small animal is 75% of the weight of the mature carcass of a large animal. The differences in body composition determine the nutrient requirements for animal growth (Berg and Butterfield, 1976; Thonney, 2004). This means that animals with the same BW, but with different mature sizes, will have different nutrient requirements.

Animal growth is determined by the amount of dietary net energy available for gain (NEg) after maintenance requirements are satisfied. NEg is defined as the energy content of deposited tissue (NRC, 1996; 2001). It represents the proportion of fat and protein in empty body tissues (Garrett et al., 1959) as demonstrated by Simpfendorfer (1974) who observed that in cattle of the same mature size, the chemical components and empty body energy varied with body weight.

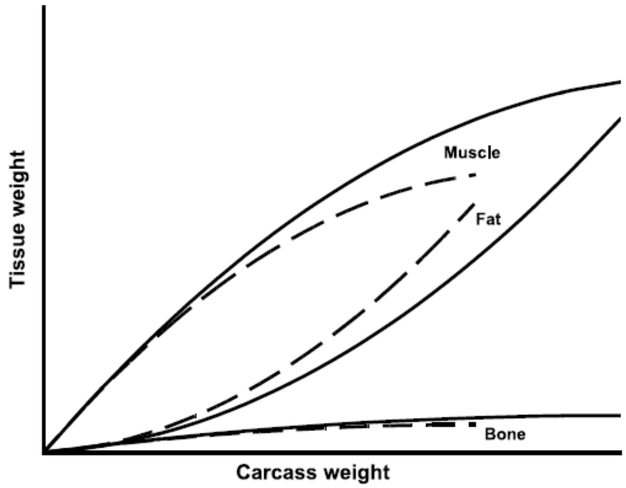


Figure 3. Growth of the carcass to mature proportions of 50% muscle, 35% fat, and 15% bone. Solid lines represent data for animals of large mature size. Dashed lines represent data for animals of small mature size. The sum of quantities of muscle, fat, and bone equal carcass weight. Adapted from Thonney (2004).

The BW at which cattle reach the same chemical composition differs according to mature size, sex and dietary intake. Hence, composition differs among breeds even when BWs are the same (NRC, 1996; 2001; Thonney, 2004). This means that the average mature BW of cows in a herd partially determines the amount of energy required at specific stages of growth and development (Van Amburgh and Meyer, 2005). Van Amburgh (2004) explained this outcome using an example of two groups of heifers weighing the same, but differing in frame sizes. Although both groups received similar chemically composed diets, the energy content of deposited tissues differed. The animals with a small frame size deposited more fat and less protein per unit of weight gain than the heifers with a large frame size at the same body weight. This expected outcome was because small-framed heifers were closer to their mature BW than the large-framed ones.

Fox et al. (2001) proposed a growth model wherein various types of growing cattle have similar chemical composition of growth at the same degree of maturity. The committee that developed the 2001 *Nutrient Requirements for Dairy Cattle* utilized the size-scaling equation to formulate diets for heifers. This equation adjusts the BW of animals of varying mature sizes to a live weight at which they are expected to have equivalent body composition: a standard reference animal. This standard reference weight (SRW) corresponds to a mature animal with an empty body weight (EBW) of 478 kg containing 25 to 28% body fat, which corresponds to a live animal body condition score of 3.0 on a scale from 0 to 5 (NRC, 2001).

Berg and Butterfield (1976) explained nutrient utilization by developing a model of animal growth across time periods of positive and negative energy balance. Vital organs have first claim on available nutrients for maintenance and growth. When animals are in positive energy balance, muscle and bone growth proceed at the same relative rates regardless of the total rate of growth. During BW loss, the proportion of muscle to bone is altered because the relative rate of muscle depletion may be affected by the intakes of protein and energy. The accretion of adipose tissue depends on the amount of energy intake, i.e., an amount exceeding the requirement for maintenance. Finally, when in negative energy balance animals start to lose BW first by depleting mostly fat and then by depleting muscle. Figure 7 shows the partitioning of available nutrients for an animal in positive energy balance and the tissue depletion priorities when in negative energy balance.

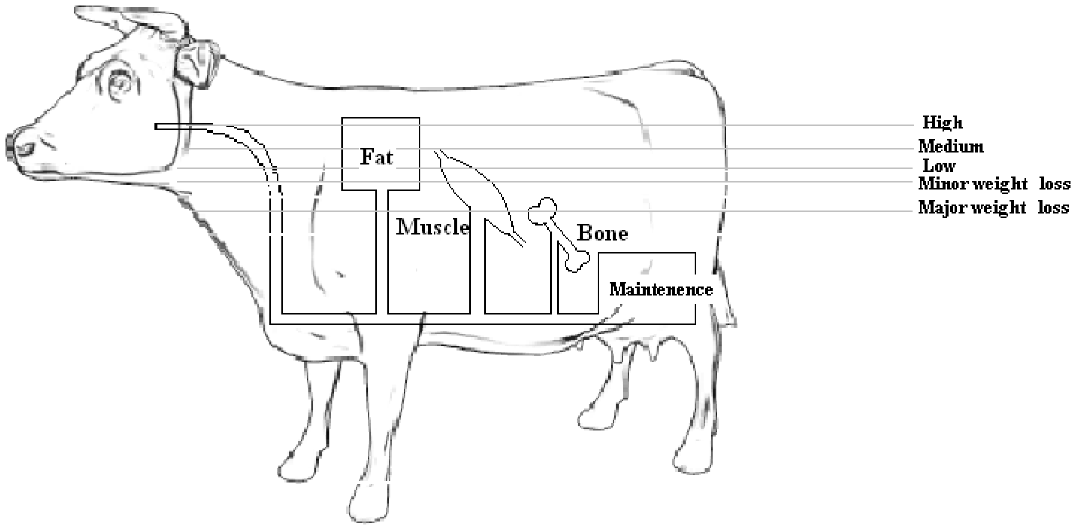


Figure 4. The model explains the accretion or depletion of tissues during growth when the nutrient supply is over (high, medium and low) or under (minor and major weight loss) maintenance requirements, respectively. Adapted from Berg and Butterfield (1976).

2.1.3. Growth rates and targets

The nutrient requirements for growing replacement heifers depend on the characteristics of the animal, its environment and management conditions (Van Amburgh and Meyer, 2005). The targets for different physiological body weights in a particular herd or population of cattle are determined by the mature size of the reared animals. Van Amburgh and Meyer (2005) pointed out that the appropriate age at first calving should be determined based on data available from a particular herd. Important information includes the management applied in the heifer program and the age at which the lifetime productivity of the heifers is optimal, given the current herd management conditions.

Heifer growth is a pliable function that can be adjusted (accelerated or decreased) according to the nutrition management program (low, medium or high nutrient intake) without effects on mature body size (Head, 1992; Macdonald et al., 2005). Thus, the sexual maturation of heifers (e.g. puberty and breeding) is more related to BW than to age (González-Stagnaro, 1983; Van Amburgh et al., 1998b). Puberty generally occurs when heifers weigh from 40% to 50% of mature BW, regardless of age (Head, 1992; Van Amburgh and Meyer, 2005). For example, when slow growth occurs in dairy heifers, the animals might not reach puberty before 18 or 20 mo of age (González-Stagnaro et al., 2007). On the other hand, if rapid growth occurs (>0.9 kg/d) during the prepubertal stage, puberty might occur before nine months of age (Gardner et al., 1977). Thus, the time delay in reaching this stage can vary considerably; heifers in the tropics are often reared on low energy and protein diets, which begets low ADG and sometimes severe delays in puberty (Maquívar and Galiana, 2006).

In temperate regions, successful breeding typically occurs when heifers reach 55% of their mature BW (Van Amburgh and Meyer, 2005; Wattiaux, 1996), which usually occurs between 12 and 15 mo of age with average growth rates of ~0.75 kg/d from plentiful feed. However, in many tropical scenarios, mating is typically delayed until the animals reach 70 to 75% of mature body weight (González-Stagnaro, 1995), frequently at 20 mo of age or older, because of insufficient feed supplies with slow growth rates of ~0.30 kg/d (González-Stagnaro et al., 2007).

Body weight at calving for heifers in DP systems should be at about 80% of mature BW (Fox et al., 2003), which can only be achieved if growth is sustained during pregnancy. Heifers attaining this BW at calving would have the ability to partition more nutrients to milk yield instead of growth during first lactation. However, constraints on growth could result in cows with smaller frame size and restricted dry matter intake (DMI) capacity, curtailed milk production and extended calving intervals (Absalon-Medina, 2008; Urbina, 1991). For heifers reared in the tropics, special attention also should be given during the transition period (last trimester of pregnancy), when homeorhesis requires complementary nutrient supplies (Mellor, 1987; Overton and Waldron, 2004).

2.1.4. Mammary development

The mammary gland is associated with functions of the reproductive system, which is affected by endocrine changes that occur with physiological maturation (Head, 1992; Wattiaux, 1996). In the bovine, mammary development is closely related to fetal development, puberty, pregnancy and lactation (Sejrsen, 1994).

The basic structures of the mammary gland are developed in the fetal stage (Forsyth, 1989; Sejrsen, 1994). During this period the non-epithelial tissues, i.e., the stroma and circulatory system, are almost fully developed, while the epithelial tissues adjacent to the gland cistern have few mammary duct cells and no alveoli formation (Sejrsen, 1994). It was believed that during the first two or three months after birth, the mammary gland structures (non-epithelial tissues) grew isometrically like overall body growth, which is similar to that observed from puberty until conception (Sinha and Allen Tucker, 1969). However, recent studies have demonstrated that, during early stages of life, epithelial cell proliferation (parenchymal growth) responds in accordance with the plane of nutrient intake by the animal (Brown et al., 2005; Meyer et al., 2006a; 2006b).

The accelerated rate of growth and development of ducts and other tissues in the mammary gland (allometric growth) occurs in two distinct phases of sexual maturation. The first phase occurs before puberty from birth until the onset of the first estrous cycle (Meyer et al., 2006a; 2006b). During this phase there is rapid growth of the fat pad, and development of the ducts that branch into it (Sejrsen, 1994). The second allometric growth phase occurs in the third trimester of pregnancy (Sejrsen, 1994; Wattiaux, 1996). During this period, there is a more extensive branching and elongation of the ducts, and ultimately the appearance of secretory alveolar cells (Sejrsen, 1994). These cells appear only during pregnancy due to the effects of progesterone and estrogen on the mammary gland (Meyer et al., 2006a).

Research findings indicated that accelerated growth reduces mammary development by increasing fat deposition in the gland during the prepubertal period (Sejrsen et al., 1983; Sejrsen et al., 1982; Sejrsen et al., 2000). However, recent studies have shown that the nutritional plan on which the heifers are reared do not measurably affect mammary parenchyma development (Meyer et al., 2006a; 2006b). Moreover, changes in homeorhetic signals produced by the animal’s nutritional status (elevated or restricted plane of nutrition), which was thought to alter indirectly the secretion rates of mammogenic hormones (Forsyth, 1989; Sejrsen et al., 2000), appear to have minimal biological effect on mammary parenchyma development (Daniels et al., 2009; Meyer et al., 2006b). Studies of Holstein heifers of high genetic merit for milk production have shown that there is only a 5 to 8% reduction in first lactation milk yield from accelerated growth (Hoffman et al., 1996; Van Amburgh et al., 1998b). Milk production decreases have been attributed to changes associated with prepubertal hormonal signals, to the rate at which puberty is achieved, and to physical condition (BW, frame size and tissue reserve status) at calving (Van Amburgh et al., 1998b). Therefore, the subsequent milking performance of accelerated-growth heifers is not significantly affected if prepubertal growth lasts long enough to allow proper time for mammary development before puberty is achieved and if heifers reach 85% of mature BW with a BCS of 3.5 and proper frame size (Van Amburgh et al., 1998b).

During pregnancy, anabolic processes concerned with growth of the placenta, fetus and mammary gland must be supported by adequate supplies of nutrients (Mellor, 1987). In the mammary gland, considerable increases in weight occur during the final trimester of pregnancy (Robinson et al., 1978, cited by Mellor, 1987; Sejrsen, 1994), which implies that during this short period the amount of nutrients required for mammary development are like those required for fetal growth (observed in sheep) (Mellor and Murray, 1985, cited by Mellor, 1987). Several studies have pointed out that the nutrient intake restriction during the final trimester of gestation considerably affects development of the gland and, consequently, subsequent milk production (Mellor, 1987; Rosso et al., 1981; Zambrano et al., 2006). In malnourished animals, significant reductions of DNA, RNA and protein content have been observed during mammary development; moreover, it has also been observed that the protein/DNA ratio is reduced, while the RNA/DNA ratio remains unchanged (Rosso et al., 1981). Histological studies in mammary glands of malnourished rats have revealed that there is a reduced number of parenchymal cells, a reduced cell size and a larger lumen within the alveoli (Rosso et al., 1981). Therefore, it is not surprising that severe maternal undernutrition during pregnancy causes a considerable reduction in the mammary growth rate (Mellor and Murray, 1985; cited by Mellor, 1987). Zambrano et al. (2006) reported effects of undernutrition during the last third of gestation in DP heifers, indicating that lower nutrient intake during this stage may affect mammary development and subsequent milk production.

In DP systems, the milk production is an important component in the economy of tropical regions. Milk yield not only influences the weaning weights of calves, but also provides extra revenue through sale of the surplus. Therefore, mammary development of DP replacement heifers plays an important role in the farm income.

2.1.5. Compensatory growth

Domestic animals experience compensatory or catch-up growth, when growth acceleration follows an early-life growth restriction. Catch-up growth generally occurs when nutrient intake restrictions are relieved, such as when the forage-plentiful rainy season begins following the low-rainfall months of the year (Heinrichs and Lammers, 1998; Ojeda et al., 2007; Park et al., 1987; Reid and White, 1977). Generally, animals exhibit compensatory growth when consuming diets that supply 15 to 40% more nutrients than required for maintenance (Head, 1992; Choi, 1997).

During compensatory growth animals experience many physiological and metabolic changes. These changes include greater BW gain, reduced initial maintenance requirements (depression of the basic metabolic rate), higher efficiency of energy for liveweight gain, greater appetite and increased feed intake capacity, altered endocrine profiles, and altered body chemical composition (compared to animals fed conventionally) (Carstens et al., 1991; Choi et al., 1997; Ellenberger et al., 1989; Ford and Park, 2001; Hayden et al., 1993; Park et al., 1998; Park et al., 1987; Reid and White, 1977; Rompala et al., 1985).

Few studies of tropical cattle production systems have incorporated compensatory growth into alternative management strategies (Ojeda et al., 2007). Variations in animal growth are attributed to the quality of tropical grasses (Urbina, 1991). Changes in forage quality has a cyclical effect on cattle grazing conditions, such that a “natural” recurring pattern of compensatory growth occurs with each transition from dry to rainy season (Almazán-Sánchez and Gallo de la Torre, 1978; Ojeda et al., 2007). These responses were observed in an experiment with steers grazing the Colombian Llanos Orientales (Paladines and Leal, 1979). Compensatory growth was seasonally associated with better grazing supplies of legumes and grasses in the rainy season, which resulted in an ADG of 0.85 to 0.90 kg/d. The rapid growth occurred immediately after the dry season, when the steers grew slowly or lost up to 0.35 kg/d. Thus, in heifers managed under grazing systems in tropical areas with rainy and dry seasons markedly defined, compensatory growth is a naturally-occurring phenomenon.

The catch-up phenomenon has been more widely studied in temperate regions than in the tropics. A catch-up strategy has been used to develop feeding programs for growing dairy (Choi et al., 1997; Ford and Park, 2001; Park et al., 1987) and beef heifers and steers (Carstens et al., 1991; Park et al., 1998; Rompala et al., 1985). These programs are based on the combination of phases with dietary energy restriction and re-alimentation (Ford and Park, 2001). For example, in the “stair step” model (Park et al., 1987) the re-alimentation phase is normally synchronized with the endocrine stages of the animal growth (Choi et al., 1997; Ford and Park, 2001; Park, 2005). Nevertheless, the degree of maturity at which growth restrictions occur plays an important role in directing compositional changes during compensatory growth (Carstens et al., 1991). This means that when nutrient restriction is imposed in early stages of maturity (i.e., a period of impetus for greater lean tissue deposition), the severity of growth restriction is heightened by a tendency for lean tissue growth to be reduced and fat tissue growth to be increased during the growth compensation period (Thornton et al., 1979). Thus, the chemical composition of growth is not only modified by nutritional means, but is also influenced by cattle type (mature size, age and sex).

The use of compensatory growth programs has shown not only similar terminal weights, but also less total feed consumption, which results in significantly improved growth efficiency compared with heifers reared in conventional feed systems targeting the same body weight at the same physiological age (Choi et al., 1997). Other systems, like limited feeding, could result in less total DMI and increased feed efficiency, which could reduce the feed cost (Hoffman et al., 2007). Hoffman et al. (2007) indicated that feeding more nutrient-dense diets to pregnant dairy heifers may be an equally effective feeding management strategy to control caloric intake, as compared with feeding high-fiber forage diets.

The composition of gain in heifers reared in the tropics undoubtedly varies considerably. The variability in the growth rate may reflect seasonal availability of forages (quantity and quality) and management decisions to adjust growth to a desired rate. Thus, based on nutritional constraints and opportunity windows for growth, compensatory growth could allow poorly growing young heifers to reach a desired breeding weight more quickly and, consequently, at a younger AFC. This practice could be of economic importance for farmers in the tropics because higher growth rates could be achieved after a nutrient restriction period (drought) by investing in diets high in energy, protein, and other required nutrients.

2.1.6. Effect of age and weight at first calving on lactation performance

Several inputs, such as disease control, genetic selection, nutrition and general management, affect lactation performance. Age and weight at first calving are important in determining how well primiparous cows will produce during the current and subsequent lactations (Head, 1992; Van Amburgh and Meyer, 2005). For example, if growth is irregular or badly controlled during rearing, then heifers may be too large or too small at specific stages such as first breeding or first calving and end up as poor replacements (Head, 1992).

Numerous reports from US dairy herds indicate that heifer replacements reared in temperate regions should enter the producing herd by approximately 24 mo. This has been assessed from a composite of economic and productive results over the years (Cady and Smith, 1996; Gill and Allaire, 1975; Head, 1992; Pirlo et al., 2000; Tozer and Heinrichs, 2001). Still, farmers may remain skeptical about such an early AFC, instead preferring to delay it beyond 24 mo to obtain larger heifers that are better able to compete in the milking herd (Pirlo et al., 2000). However, these approaches have numerous disadvantages since with older replacements nonproductive lifetime is lengthened, and the income from milk and calf sales is delayed. (Cady and Smith, 1996; Pirlo et al., 2000; Tozer and Heinrichs, 2001). Furthermore, the assumption that heifers at older ages are going to have a larger frame size, will only be true if they grow quickly; if not, size advantages will go unrealized (Head, 1992).

Meyer et al. (2004) noted that the biology involving interactions between reduced AFC and first lactation milk yield has been challenging to understand. Yet, the relationship between the reduction in AFC and increased prepuberal daily gain and/or reduced body weight at calving has been shown to influence future milk yield (Meyer et al., 2004). Although BW at calving has been positively correlated with first lactation milk yield (Van Amburgh et al., 1998a), Hoffman et al. (1996) suggested that replacement heifers with similar prepartum BW will not always be similar in first lactation milk production. They suggested factors such as skeletal size and body composition (tissue status) also need to be considered in assessing optimal body size of replacement heifers.

Inconsistencies about animal measurements are common in the tropics. Avila (1995) analyzed weight at different ages in a DP herd (Brown Swiss or Holstein × Zebu) in Veracruz, Mexico. The average weight at mating of 25 Brown Swiss × Zebu heifers was 363 kg at 25 mo of age. These animals had an ADG of 0.50 kg from six months to 25 mo of age. He found that their average weight at about 1 or 7 days precalving was 415 kg, but once the fetus, placenta and amniotic fluid weights (50 kg) were subtracted from the heifer's weight, the average weight was 365 kg, which was just two kilograms more than the weight at mating. The same author reported a similar finding in 40 Holstein × Zebu heifers, whose weight at mating was about 359 kg and reached 400 kg one week precalving. However, after calving these animals actually weighed about 9 kg less than their breeding weight (350 kg).

Generally, DP heifers have low BW at first calving, which influences subsequent animal performance. Deresz et al. (1987) evaluated Holstein × Zebu heifers from puberty to first calving at two levels of energy intake (diets not defined). These heifers were mated at 350 kg of BW. Thereafter, half of them were fed a low-energy diet, which resulted in BW of about 400 kg (light heifers). The counterparts were fed a high-energy diet, which resulted in an average BW at calving of 464 kg (heavy heifers). The responses were lactations of about 156 days in length with milk production of 1,283 kg for the light heifer group compared to the heavy heifer group, which produced 2,132 kg milk in lactations averaging 239 d. Moreover, during the second lactation the light group did not grow, remaining at a BW of 400 kg. This research team pointed out that the mismanagement of growing animals not only affects the first lactation milk yield, but also the cow's future life performance.

Management conditions in the tropics generally delay calving age above 36 mo. Additionally, the slow growth rates that these animals experience during the prepubertal and postpubertal periods result in thin heifers calving with low BW, which translates into poor productive and reproductive performance as cows. To assure more milk and calves per cow in DP cattle systems, it is important to consider how to economically manage heifers to calve at younger ages with heavier BW and larger frame sizes (Urbina, 1991). This should improve the potential for greater lifetime cow performance with more milk and calves per cow (Absalon-Medina, 2008).

2.2. Quality of tropical grasses

Forage from grasses represent the main feed for cattle in the tropics because of its low cost when available (Juárez-Lagunes et al., 2002a). Nonetheless, forage quality is variable throughout the year, which produces fluctuations in cattle performance (Absalon-Medina, 2008; Baba, 2007). Grasses have specific physiological and morphological characteristics of adaptation to certain climatological conditions, which support their growth (Pirela, 2005). Nevertheless, when factors such as high temperatures and high or low rainfall are present, the growth of the plant is adversely affected, producing morphological modifications that affect quality and yield. One such change is the production of secondary compounds that depress their digestibility (e.g., lignin, tannins) (Pirela, 2005; Van Soest, 1994).

Seasonal variations in forage quality have been identified that limit cattle performance, as in the warm Mediterranean region of Sicily, Italy (Licitra et al., 1998). Such changes in forage quality were observed to influence the growth of heifers, which, in turn, affected AFC. Results showed that cattle performance was markedly reduced during the dry season due to the pasture quality. These pastures had high contents of neutral detergent fiber (NDF) and lignin, and low crude protein (CP), which decreased the forage digestibility. Similarly, in Veracruz, Mexico, Juárez et al. (2002) showed that rapid growth and maturation of tropical grasses incurred rapid declines in chemical composition (e.g., high lignin, high NDF and low CP) and digestion rate.

Growth and chemical composition of tropical pastures is also influenced by the amount and frequency of rainfall. An excess or deficit of water stresses the plant, which limits the nutritional quality of the subsequent feed (Pirela, 2005; Van Soest, 1994). In western Amazonian Brazil, Rueda et al. (2003) pointed out that forage chemical composition during the rainiest months resulted in considerable nutrient deficiencies for steers and DP cows. They found more NDF and neutral detergent insoluble protein (NDIP) and less metabolizable energy (ME) in the rainiest months than in the less rainy ones. Lower predicted dietary energy and protein intake resulted in lower predicted weight gain (20% less) in growing steers. On the other hand, in Veracruz, Mexico, Esqueda-Esquivel et al. (2007) carried out a series of forage analyses (African star grass; *Cynodon plectostachyus*) in different seasons of the year. They reported that the forage quality and quantity during the dry season is seriously compromised due to the lack of water and high temperatures. They observed that the content of NDF and lignin was high, while the CP content was low. Therefore, the productivity of DP cattle in Veracruz is undoubtedly constrained by seasonal variations in the quality and quality of its forage supplies (Absalon-Medina, 2008).

2.3. Dietary constraints on growing cattle

A few studies have been conducted in tropical Latin America to determine the nutrient requirements of DP cattle systems. Most of these have pointed out energy intake as a key determinant of the productivity and profitability for DP lactating cows (Absalon-Medina, 2008; Baba, 2007; Nicholson et al., 1994; Reynoso-Campos et al., 2004; Rueda et al., 2003). However, in a study in Veracruz, Mexico, the crude protein (CP) was also found to be a primary dietary limitation (Juárez et al., 1999).

The information available about the primary nutrient constraints in heifers reared in the tropics is limited. However, several studies from temperate climates have demonstrated the utilization path of energy and protein during the physiological maturation of replacement animals. It has been shown that the deposition and use efficiency of dietary protein for growing heifers is high during the early stages of life, but as the animal matures, the amount of energy required for a targeted daily gain increases (NRC, 2001; Van Amburgh and Fox, 1996).

In the tropics, research has been conducted on the nutrient constraints of immature cows (first or second lactation) that are still growing, and less, if any, has been focused on younger animals (from weaning to calving). Generally, DP heifers in the tropics start the first lactation with very low body weights, as a result of the low growth rates during pre- and postpuberty stages (Absalon-Medina, 2008). The ADG of growing animals is constrained by the low nutrient content of grasses (Juárez-Lagunes et al., 2002a), which delays the onset of puberty. Deresz et al. (1987) analyzed the effect of two planes of energy intake on crossbred heifers from conception (350 kg of BW; ~65% of MBW) to calving. Animals reared on low energy diets calved at 70% of MBW (<400 kg) and animals that were fed higher energy diets and achieved about 85% of MBW (~460 kg). These authors concluded that animals with low BW at calving had reduced first lactation milk yield, but also that the subsequent productive life of the animal was reduced.

As previously indicated, dietary intake restrictions occur widely in DP systems, especially during the dry season. In Yucatan, Mexico, nutritional constraints were evaluated in beef rearing systems, where herd management restricted daily feeding time to about 12 h (Baba, 2007). The corresponding DMI resulted in low energy intakes during first and second lactations, which severely constrained the growth of immature cows. The amount of energy supplied in the diets of these cows was insufficient to maintain milk production, making it necessary to rely on mobilized body reserves. Consequently, these animals tended to have long calving intervals because of the delayed time to achieve target live weights for subsequent productive cycles, which probably reduced cows' productive life (i.e., fewer lactations, less milk production and fewer calves). The author concluded that a greater feed nutrient intake would reduce the reliance on body tissue reserves during lactation, which would also signify shorter calving intervals.

Another dietary constraint is the inadequate management of the stocking rate capacity of native grasses. In an experiment carried out in the lowland savannah of Colombia, three groups of Brahman heifers were raised at different stocking rates from weaning to a target weight of 270 kg (Vera et al., 1993). All the groups grazing low-quality *Brachiaria humidicola* experienced undernutrition effects from alternative stocking rates. Average daily gains were 0.097, 0.215 and 0.259 kg. Once animals reached the target weight, they were transferred to a common paddock with low-quality *Brachiaria humidicola* and received a mineral supplementation of 80 g/kg of phosphorus and other macro- and micronutrients. The ages at calving were 50, 40 and 41 mo for heifers reared under high, medium and low stocking rates, respectively. These results indicate that heifers with severe undernutrition in early life were older at calving ($P<0.001$); moreover, older heifers at calving had shorter productive lifetimes with fewer calvings (~3) than better-fed heifers (~4).

In addition to insufficient management attention to growing animals, severe constraints have been identified during the transition period of young animals.

Absalon-Medina (2008) found in DP systems in the leeward region of Veracruz, Mexico, that cows of all ages had severe energy deficits during the last third of gestation. He pointed out that ME dietary supplies from grasses were insufficient for desired growth of immature cows. Such growth constraints resulted in smaller cows with less DMI capacity, curtailed milk production and delayed postpartum return to ovarian cyclicity (longer calving intervals).

Further research in dietary constraints on growth and the transition period of heifers is needed for farmers that raise animals in the tropics in order to achieve better replacement animals. To have a better idea of the primary nutrient constraints on growing cattle, especially replacement heifers, requires defining animal, management and environmental factors and then defining the chemical composition of the feed in a manner consistent with utilization by a ruminant (Van Amburgh and Fox, 1996). The systematic evaluations of herd management opportunities and options should include explicit considerations of growth to achieve better body size goals and younger ages at calving. Cows that target better BW and frame sizes will able to consume more DM and possess better tissue reserves to support higher milk yield than smaller cows with low BW (Absalon-Medina, 2008; Urbina, 1991). Appendix 4 summarizes nutritional constraints and management options for tropical DP replacement herds.

2.4. Alternative grass species for improving dietary nutrient intake

Most feeding systems in tropical Latin America are based on native grasses, which often supply insufficient dietary nutrients to meet the nutrient requirements of cattle to produce milk and beef. Therefore, the introduction of high-yielding forage varieties containing more energy and protein for animals in DP systems could allow better growth performance and higher BW for milk producing heifers and beef steers in DP systems.

In recent decades, the International Center of Tropical Agriculture (Centro Internacional de Agricultura Tropical; CIAT), through the tropical forage project, has identified and characterized forage grasses adapted to a wide range of edaphic and climatic conditions. New cultivars are increasingly being adopted, which has significantly improved the forage quality on regions of Panama, Mexico, Colombia and Central America (Argel, 2006).

CIAT has evaluated and developed new grass cultivars from selected *Brachiaria* spp. These cultivars have shown good adaptation to tropical conditions and better cattle production. Improved varieties, such as *Andropogon gayanus*, with its higher digestibility, have resulted in greater productive and reproductive performance of cattle than those obtained from native species (i.e., *Cynodom plectostachyus*) (Argel, 2006).

One of the *Brachiaria* cultivars recently developed by CIAT is the cv. Mulato II. This new cultivar, like cv. Mulato I, is a hybrid from *Brachiaria ruziziensis* × *Brachiaria brizantha*, also called *Brachiaria* hybrid. It has been identified as an outstanding grass, since it is more resistant to higher stocking rates (major biomass production), to longer drought periods (deeper rooting system), and to poorer soils (better adaptation to marginal soils). With these characteristics this cultivar has resulted in better cattle productivity than other *Brachiaria* spp (Argel et al., 2007).

The quality of the cv. Mulato II has been compared with other grass species by CIAT at the research station in Santander de Quilichao, Colombia. It has shown better average CP content (11.4%; $P<0.05$) than those averages obtained from the cv. Toledo (9.1% of CP) or cv. Mulato I (9.7% of CP), during the rainy and dry seasons, with a stocking rate of 3 animals/ha. The yield per hectare and DM digestibility were not different between varieties, although DM digestibility was low during the dry season in all cultivars.

Several studies have shown the positive effects of using improved grasses on milking cows. Evaluations have demonstrated increases of more than 10% in milk production when cows are grazed, dry or rainy season, in paddocks with cv. Mulato compared with other *Brachiaria* spp (CIAT, 2004; 2005; Guiot, 2005).

Research studies using new grass varieties were conducted at IDIAP[6] (Pinzón and Santamaría, 2005) and CORPIOCA[7] (Cuadrado et al., 2005) to evaluate the growth of Zebu crossbred steers. Both sites utilized rotational grazing as their management system. Steers in Panama grazed each paddock for 3 days and then each paddock was allowed 21 days of recovery. In Colombia, animals grazed about 2 days followed by 22 days of recovery for the rainy season, and 3 days of grazing with 33 days of recovery during the dry season. Both studies utilized similar average stocking rates (3.4 vs. 3.5 AU/ha in Panama and Colombia, respectively) for cv. Mulato, although weight gain per animal was slightly higher in Panama (0.54 kg/d) than in Colombia (0.50 kg/d). In Panama, steers used were crossbreds of Zebu with initial BW of 183-206 kg, while in Colombia the steers used were Zebu breed and crosses (F1) of Zebu × Romosinuano, with an average initial body weight of 285 kg. The latter had higher ($P < 0.05$) daily gain (0.57 kg/d) than the Zebu breeds (0.41 kg/d). In Colombia, the cv. Mulato showed better production parameters for the animal stocking rate and beef production per ha/year when it was compared with the cv. Basilisk managed in similar conditions, although the average daily weight gain was similar for both types of pastures (0.50 *vs*. 0.53 kg/d, respectively; $P<0.05$).

[6] Institute of Agricultural Research of Panama
[7] Colombian Agricultural Research Corporation

In Isla, Veracruz, Mexico, two groups of steers (BW not specified) were randomly assigned to either Mulato or *Brachiaria decumbens* (Signal grass). The stocking rate was 4 AU/ha. Animals that grazed cv. Mulato grew more rapidly than those that grazing Signal grass (0.30 kg/d *vs*. 0.22 kg/d, [significance was unreported]). The daily gains are not surprising, but when these grasses were compared in terms of productivity per hectare, the cv. Mulato showed 555 kg/ha of annual live weight gains, which was superior to the gains obtained for Signal grass, 219 kg/ha (Enriquez, 2002 [reported in Guiot and Melendez, 2003]).

In the Latin American tropics, feeding quality is a primary limitation on cattle production. The low quality of native forages provide insufficient supplies of dietary energy and protein, which leads to lower average daily gains and, consequently, delays in AFC. Herds reared on native pastures generally have lower performance than animals managed on grasses of higher quality, which better meet animal requirements. To develop nutritional management strategies, especially for DP herds, researchers need to focus on animal groupings differentiated by physiological stages of growth or productivity, breed type, environment inputs and chemical composition, and digestion rates of feedstuffs used in the diets to account for the main nutrient requirements for a specific cattle stage. This basic information gathered and organized into an effective managerial protocol for technical implementation in target farms or agroecozones will provide farmers with the means to improve animal productivity and profitability.

2.4.2. Use of legumes to feed dual-purpose heifers

In tropical and temperate regions, the integration of legumes has shown improvements in basic diets and overall animal production, when compared to grass-only management systems (Jones, 1994; Ramírez-Restrepo and Barry, 2005). Some legume forages have secondary compounds, which allow a major supply of essential amino acids to be absorbed by the small intestine through rumen-protected transport (Cannas, 2001). Consequently, improvements in growth and lactation performances might be expected for juvenile and lactating animals (Shelton, 2004).

The integration of legumes into grazing systems has enhanced overall forage digestibility by increasing the particle breakdown, rumen fermentation, and passage rate, which improves voluntary feed intake (Ramírez-Restrepo and Barry, 2005; Shelton, 2004). These improvements have been observed when the inclusion of increased levels of legumes into forage diets (>20% of DM) provide adequate pH and more NH_4 (Vergara-López et al., 2006) for rumen fiber carbohydrate bacteria. Furthermore, Vergara-López et al. (2006) showed that more stable rates of ruminal ammonia production and ruminal pH were obtained when ruminants grazed on intercropping systems than when legumes were supplied as protein banks (restricted feed intake). These authors also pointed out that there are better supplies of protein through the day when animals graze intercropping systems than when animals are supplemented once a day with commercial concentrates or are grazed on protein banks for restricted periods. On the other hand, grass-legume associations have been shown to provide other benefits to the system such as by fixing atmospheric nitrogen in the soil and by reducing emissions of greenhouse gas (methane) from improved forage digestibility, which may result in more sustainable livestock production systems (Cannas, 2001; Ramírez-Restrepo and Barry, 2005; Shelton, 2004).

The tropical regions of Mexico generally have a dry period that lasts approximately six months (Magaña-Monforte et al., 2006). This results in severely constrained diets from shortages in amount and quality of available forage, which generally comprises mature and fibrous grasses or crop residues. Thus, diets are characterized by high content of structural carbohydrates and low contents of nitrogen, non-structural carbohydrates, lipids and essential minerals, which frequently make them a poor rumen supplier of available nutrients (Juárez-Lagunes et al., 2002a). In addition, small quantities of these feedstuffs cannot provide sufficient nutrients to catalyze rumen fermentation and maintain microbial growth (Leng, 2003 cited by Shelton, 2004). Therefore, during the dry season supplementation is required to provide minerals and proteins to the rumen, which promotes digestibility of fibrous carbohydrates. Leng (2003; cited by Shelton, 2004) indicated that the use of forages with >15% crude protein, from which a high percentage was by-pass protein (>50%), could increase bacterial growth and promote live weight gains in animals grazing poor quality diets.

In tropical settings, tree legumes have shown better adaptation to grazing systems than herbaceous legumes, since there are tree legumes species that retain their foliage and quality during drought conditions (Shelton, 2004). One clear example is *Leucaena leucocephala*[8], whose rooting characteristic (between 5-6 m) enables cattle to obtain extra protein during dry periods. Forage protein in the dry season promotes rumen microbes and overall better digestion of low quality roughages (Shelton, 2004).

The major anti-nutritive constituents in some legume species for ruminants are condensed tannins (CT). These molecules have the capacity to bind proteins, and to incur negative effects on protein utilization (Cannas, 2001). However, it has been observed that the binding capacity of CT is seriously affected by the pH of the reaction environment. Osborn (2000) measured the ability of CT to precipitate protein from different cultivars of leucaena (*Leucaena leucocephala*). He found that CT has the

[8] Legume native from southern Mexico and Central America, which grows on neutral and alkaline soils throughout the tropics between 30°N and 30°S latitudes, and at elevations up to 1500 masl (Hill, 1971; cited by Garcia et al., 1996).

ability to precipitate protein at a pH reaction environment of 5.0. The increase or decrease in the pH from 5.0 reduced the ability of CT to precipitate protein. Thus, leucaena's CT completely lost its capacity to precipitate protein when the pH was about 2.5 (e.g., abomasum pH). This suggests that the complexes formed by the legume's tannins have potential for increasing the supply of feed protein escaping rumen degradation. These proteins are released in the abomasum, which increases the feed protein digestion in the small intestine and the total amount of protein absorbed by ruminants. Chongo et al. (1998), studying "in situ" degradability of leucaena's nitrogen, observed an effective degradation of about 53.7% (cited by Ruiz et al., 2006). These values suggest that for each 100 g of DM protein consumed by the animal, about 54 g are degraded in the rumen and 46 g escape the rumen (by-pass protein) and are absorbed in the small intestine.

Studies from tropical regions have pointed out that the use of tree legumes could promote good ADG and reduce commercial supplementation, and consequently production costs of DP heifers. Animal performance data varies according to treatments of leucaena with molasses-urea, with freshly chopped sugarcane, or with intercropping (leucaena/grasses). In a study carried out in the Dominican Republic, Creole or Creole × Holstein bulls from 80 to 300 kg BW at 1 or 2 years old were used to compare treatments with leucaena and groundnut cake as sources of protein (Hulman et al., 1977). The basic diet of these animals consisted of *ad libitum* intake of a mixture of molasses containing 3% urea and a grass of poor quality (*Ischnemum aristatum*). In treatments 1, 2 and 3, fresh leucaena was supplemented in proportions of 2%, 3.5% or 4.6% of the animal BW, whereas in trials 4 and 5, the amount of groundnut cake in the diet was adjusted to supply the same amount of protein as in treatments 1 and 3. The results showed that ADG for treatments 1 to 5 were 0.791, 0.737, 0.848, 0.595 and 0.744 kg/d, respectively. These authors concluded that the most economical level of leucaena supplementation was 2% of BW (fresh basis).

Ruiz et al. (2006) cited a study in which developing heifers were grazed in intercropped paddocks of leucaena/grass with stocking rates of 2.5 AU/ha. These animals were rotated in six unfertilized paddocks and did not receive commercial supplementation. The results showed an ADG of about 0.50 kg/d, with mating at 22 mo of age at more than 300 kg of BW. In another study reported by these authors, growing steers weighing 150 kg were grazed in paddocks of native grasses and leucaena at a stocking rate of 2 AU/ha. The ADG obtained were about 0.60 kg/d since these animals received a supplementation based on chopped sugar cane and 3% urea during the dry season.

Experimentally, the association of legumes and grasses has the potential to improve ruminant production. However, in practice, the management of this association faces several problems, especially under grazing conditions (Roberts, 1978). One concern is the growth biology of each plant species, which is faster in C_4 grasses than in legumes. This means that without proper management, the grass/legume ratio could be difficult to maintain under grazing conditions (CIAT, 2000; Morales, 1989; Roberts, 1978). For example, when legumes such as *L. leucocephala* (tree legume) are associated with tropical grasses, adjustments in grazing management have to be considered to allow for a legume re-growth of 42 to 56 days (Juárez-Lagunes, 2002a; Garcia, 1996). Although the nutrient content of the grass is sacrificed, the productivity of the grass-legume association is greater than from only grass (Roberts, 1978). Moreover, the addition of legumes to the grazing systems incorporates nitrogen into the paddock, reducing in this way the need for nitrogen fertilization (Morales, 1989).

The use of legumes to feed growing heifers could be an excellent alternative because it reduces the nutritional deficiencies and diminishes the production cost. However, more information and research is necessary to evaluate the best way to use these alternative forages. Shrub or herbaceous legumes could be successfully used in association with tropical grasses, if farmers sacrifice the nutrient content of grasses to be grazed, and have greater productivity than from grass-only pastures. Moreover, tree legumes have the characteristic of resistance to large droughts since these species have the ability to search for water through deep root systems. Thus, tree legumes can maintain quality and DM supply through the dry season, when grasses could reduce their DM supply by 75% under these conditions.

2.4.3. Sugar cane as a supplement during the dry season

Sugar cane (*Saccharum officinarum*) is an important feedstuff for DP cattle in subtropical and tropical regions. Some of the advantages as a forage crop include easy adaptation to tropical environments; less sensitivity to poor soil fertility, hot-humid climate, and pests and disease problems than other tropical plants; high yield capacity; and ability to maintain quality as a standing crop in the field for many months after maturity (Collao-Saenz et al., 2005; Pate et al., 2002).

Sugar cane maturity is an important issue at harvesting, since vegetative young plants have less total digestible nutrients (TDN) than old plants. In a study at AREC-Belle Glade, cited by Pate et al. (2002), different sugar cane varieties were tested to determine the effect of maturity on potential nutritive value. Whole plants were first harvested on April 9 (age not indicated at harvesting), when they had mostly leaves with small stalks, and subsequently at 56-day intervals for a 336-day period. Laboratory results showed that as plants matured, the dry matter (DM) content increased, and the crude protein (CP) and fiber content (NDF and ADF) decreased. *In vitro* digestible organic matter consistently increased with the aging plant (Pate, 1979 [reported in Pate et al., (2002)]). These results showed the importance of sugar cane maturity in terms of feeding cattle.

Sugar cane, as standing forage, has a great advantage since this crop has the ability to increase in digestibility and to maintain its high quality over an extended period. These characteristics offer substantial advantages in the use of sugar cane as a cattle feed during periods of forage scarcity such as the dry season of the year. Furthermore, the time for harvesting is during the dry season, which insures maximum sugar content in the stalk (Pate et al., 2002).

In AREC-Belle Glade, several trials were conducted feeding fresh-chopped sugar cane at different levels in feedlot type diets (Pate et al., 2002). The ratio of sugar cane in the diet was from 20 to 77% of the DM with the remainder supplied by corn grain, citrus pulp and cottonseed meal. The results showed that as the percentage of sugar cane in the diet increased, rate of gain, feed efficiency, and carcass quality decreased. Steers fed with a diet containing 77% sugar cane on a DM basis gained weight 30% slower and 30% less efficiently than those fed with 75% corn silage diets. Furthermore, increasing levels of cane in the diet also resulted in DMI constraints, which was associated with the low digestibility of its fiber (bagasse) (Pate et al., 2002).

In another feedlot trial at AREC-Belle Glade that compared fresh-chopped sugar cane and cottonseed hulls as roughage, 12 mo old steers were fed a high-concentrate of growing and finishing diets. The diets were formulated such that both roughage ingredients supplied the same amount of NDF to the diet to which they were added. The results indicated that during the growing phase steers fed with sugar cane diet gained 11% slower than steers fed the cottonseed hull diet. Most of this response was justified by an 8% depression on DMI by steers fed a sugar cane diet. During the finishing phase, the roughage source was reduced to one-half of the diet. The rate of gain was similar in both trials. However, steers consuming sugar cane had 12% higher DMI and 12% lower feed efficiency in converting DM to gain than steers consuming cottonseed hulls (Pate et al., 2002).

Undoubtedly, one of the main constraints of the chemical composition of sugar cane is its low CP content. Moderate levels of CP could be obtained from plants harvested at a young age. However, Pate et al. (2002) pointed out that harvesting young plants would have counterproductive results, since yield and digestibility of the cane would be seriously constrained. This nutrient constraint in the sugar cane chemical composition requires the addition of supplemental nitrogen, when cane is used for feeding cattle (Aranda et al., 2001; Pate et al., 2002). Non protein nitrogen (NPN) sources, such as urea, can be used as a supply of CP in diets containing sugar cane; nonetheless, animals have better performance when natural protein feedstuffs are supplied (Pate et al., 2002). Aranda et al. (2000) tested the effect of sugar cane offered as 3% of the BW (242±13 kg initial BW) with or without urea (1%) and with a protein supplement[9] (1 kg/d) on the performance of 32 crossbred heifers (*Bos taurus* × *Bos indicus*) grazing star grass. The results showed that heifers receiving the protein supplement had better ADGs (0.53 kg/d; $p<0.01$) than those that received the other treatments (control group 0.32 kg/d; sugar cane without urea 0.33 kg/d; sugar cane plus urea 0.37 kg/d). Thus, the authors concluded that whole sugar cane offered at 3% of the BW (urea at 1% of the sugar cane as fed) supplemented with a protein

[9] Supplement contained as DM basis: 10% blood meal, 50% poultry letter, 25% rice polishing and 25% cane molasses.

concentrate could improve the ADG of grazing heifers in the humid tropics during periods when forage availability is critical.

In tropical regions, the cost of producing sugar cane is usually much lower than the cost of commercial concentrate. Pate et al. (2002) economically analyzed the performance of steers fed diets containing 20 and 77% of sugar cane DM. The ADGs were changed to 1.6 kg/d and 0.86 kg/d for the 20 and 77% sugar cane diets, respectively. The results showed that net returns above feed costs were higher for steers fed with the high level of cane, irrespective of concentrate price. The use of sugar cane in tropical diets is economically feasible for growing cattle in developing countries in the tropics.

2.5 Application and evaluations of the Cornell Net Carbohydrate and Protein System in the tropics

The Cornell Net Carbohydrate and Protein System (CNCPS) is a mathematical model developed to predict cattle nutrient requirements (i.e., maintenance, growth, pregnancy, lactation and tissue reserve mobilization), feed utilization, and nutrient excretion (Fox et al., 2004). This computational software has been used mainly in temperate herds, but there are some studies in tropical herd production conditions (Absalon-Medina, 2008; Baba, 2007; Juárez et al., 1999; Reynoso-Campos et al., 2004; Rueda et al., 2003).

Juarez et al. (1999) utilized the CNCPS to characterize the carbohydrate and protein fractions as well as the digestion rates of 15 tropical grasses grown in Veracruz. They evaluated the grass chemical composition to determine the potential of these grasses to support milk production in DP herds, finding that changes in the nutrient fractions and digestion rates have considerable effects on milk yield. These researchers concluded that the CNCPS can be used to describe animal nutrient requirements and develop feeding recommendations for tropical animals, if adequate forage analyses are available.

In Rio Branco, Acre, Brazil (western Amazon region of Brazil) Rueda et al. (2003) investigated strategies to improve productivity and economic returns of dual-purpose (*Bos taurus* × *Bos indicus*) and beef (Nellore) cattle grazing *Brachiaria decumbens* and *Brachiaria brizanta* cv. Marandu and *Pueraria phaseoloides* (tropical kudzu). Milk production and growth responses were measured to predict animal productivity responses to dietary nutrient availability throughout the year. Using the CNCPS, subtle differences were detected in grass chemical composition between seasons that resulted in less metabolizable energy (ME) available for growing steers. The authors concluded that sorghum supplementation was necessary to increase milk production and growth rate by 25 and 50% per animal, respectively. This alternative supplementation was less profitable than increasing the stocking rate (from 2 to 4 AU/ha) with well-managed fertilization of grass-legume pastures, which resulted in greater net margins for beef producer farmers (growing cattle) but not for milk production.

Reynoso-Campos et al. (2004), Baba (2007), and Absalon-Medina (2008) used approaches to systematically evaluate productivity limitations and potentials of tropical herds in Mexico. They used the CNCPS to evaluate and identify nutrient constraints from typical management on tropical herds by analyzing the chemical composition of forages, animal and environment inputs. These approaches are fundamental for also understanding and identifying bottlenecks for DP heifers reared in the low Huasteca (Northern Veracruz) region of Veracruz.

2.6. Economic assessments of rearing heifers

The profitability of the heifer enterprise results from an integration of our understanding of the biology of heifer growth and the management necessary to accomplish appropriate growth in the most timely and cost effective manner (Van Amburgh and Tikofsky, 2001). The heifer rearing program represents the second largest capital expenditure on a cattle farm, followed only by feed cost for the milking herd (Cady and Smith, 1996; Heinrichs, 1996). A basic approach to minimizing this cost is to reduce the amount of time between the heifer's birth and her first calving (Heinrichs, 1996; Meyer et al., 2004). Cady and Loney (unpublished, cited by Cady and Smith, 1996) showed the extra cost of delaying AFC in heifers. They reported that an extra day of AFC costs approximately twice as much as an extra day dry and 13 times as much as an extra day open. Since older heifers accumulate extra rearing costs, it is economically more efficient to grow heifers during the period of time when they are physiologically and metabolically more efficient, than to wait until after calving when they have entered lactation and have to partition nutrients to other functions besides growth.

Cady and Smith (1996) indicated that an increased AFC increases herd costs in three ways: increasing days of rearing, increasing numbers of replacements on the farm, and losing production potential. For the first point, it has been demonstrated that it is economically efficient to feed heifers on a high plane of nutrition and reduce the number of days to calving (Cady and Smith, 1996; Pirlo et al., 2000; Tozer and Heinrichs, 2001). Under suboptimal feeding, daily expenditures for feed cost decrease, but the extra days needed for growth and maturity more than offset the cost saving. Tozer (2000) used a linear and stochastic programming model to determine the cost of Holstein dairy heifers per day. He noticed that the extra average cost per day to grow heifers from a suboptimal to an optimal average daily gain was $0.04/d. The difference in feed cost to obtain a heifer of 22 or 24 mo AFC versus a 26 to 28 mo AFC required an extra expense of $40. However, when he calculated the total cost of raising a heifer, the increased cost per day for an AFC of 22 or 24 mo was offset by the increased total feed costs for an AFC of 26 or 28 mo, which was $70 to $120 less than the difference per head for older AFC heifers.

Improvements in tracking and management of the heifer enterprise provide an excellent opportunity for financial improvement on farms. Cady and Smith (1996) illustrated rearing expenditures by comparing heifers calving at 24 and 30 mo of age. Their results showed that heifers calving at 30 mo were expected to outperform those calving at 24 mo by producing more milk during first and subsequent lactations, producing about 4000 more pounds of milk at the end of the fourth lactation. However, older animals had six more months of raising costs than the younger animals, and in addition, as the cow's age, the effect of AFC on milk production diminishes (just 254 lbs of difference during the fourth lactation). When the cash flow for milk at a $3 margin, and $1.45 per day of rearing cost were considered, they showed that advanced AFC increased the cost on the farm (Cady and Smith, 1996). This increase was due to the extra days that the old heifers spent in the rearing pen compared with those 24 mo age. Moreover, older heifers did not produce enough milk to make up for the difference in rearing cost for the additional 6 mo of age even though they produced more milk and generated more income during lactation.

When animals of different AFC are compared at a fixed age, animals with younger AFC will have greater production than older animals (Cady and Smith, 1996). This is because younger animals will have produced more income due to the increased number of productive months than the old heifer. Furthermore, if the breakeven cull age[10] is measured, the animals with younger AFC will have to remain in the herd less time than the older animals (Cady and Smith, 1996).

On the other hand, when heifers in a herd are calving at ages older than the targeted ones, an increase in the inventory of heifers will be needed to replace old cows (Tozer and Heinrichs, 2001). Cady and Smith (1996) explained the association of rearing extra heifers with the increase in AFC that accompany increases in feeding costs. They found that the number of heifers required to maintain a constant herd size depended on three variables: 1) replacement rate (culling rate of old cows), 2) mortality rate of heifers, and 3) AFC. Using these variables and hypothesizing a DP herd of 100 cows, with an average AFC of 28 mo and a 25% replacement rate. Based on these data, 25 heifers will be required annually to maintain the herd size. If heifers are calving at 28 mo, this means that animals with a range in age from 17 to 28 mo are going to be incorporated in the current year; those from 3 to 16 mo of age will enter the herd in the next year; and animals younger than 3 mo will enter after 2 years. In total, 64 heifers will be required between the newborn and ready to calve ages on this farm. Given an average death rate of 10%, it will be necessary to increase the replacement herd to 70 animals. Using the same assumptions, but with animals calving at 36 mo, a total of 91 replacements will be needed to maintain herd size (Appendix 5). This increase in replacement herd size means increased feeding costs because of the extra 21 heifers required.

Similarly, Tozer and Heinrichs (2001) developed a dynamic programming model of a dairy replacement herd with Pennsylvania and US average information. The objective was to analyze the impact of different variables on the cost of rearing heifers for a representative herd of 100 cows. The authors used an AFC of 25 mo,

[10] Is the age at which an animal can be culled and her income (milk and calves), including her salvage value is sufficient to recoup her rearing cost.

calving intervals (CI) of 13 mo, herd-culling rate of 25%, and preweaning calf death (PDR) of 10% as the base comparison. They examined impact factors like AFC, CI, PDR, and the number of replacements required and concluded that the number of replacements required to maintain a herd size and the AFC are the two management factors that most affect the cost of raising replacement heifers. The replacement rate affected the cost of replacement heifers since a high replacement rate requires more replacements to be raised until calving, which implies more food expenses. On the other hand, a lower replacement rate requires that fewer replacements be reared and allowed the farmer to sell excess heifers at the most profitable age at which they could generate the most revenue.

In dual-purpose rearing systems, there is a clear need for information about management costs of growing animals. It is very common to observe that replacement heifers are the most overlooked animals in this husbandry system. The low input feeding management consistently shows that heifers in Latin American DP herds tend to average more than 36 mo AFC. Yet, there is not a clear recommendation for an optimal age at first calving of dual-purpose heifers to maximize profit. Therefore, current situations need to be systematically evaluated to determine management scenarios for the best age at first calving, which might result in more profitable outcomes.

3.0 Objectives

The overall objectives of this study are to determine the probable nutrient requirements and to systematically evaluate the likely limitations and growth potentials in heifers reared in DP systems of the low Huasteca region of northern

Veracruz, Mexico. Specific management goals are to accelerate average growth rate to reduce ages at puberty, conception and first calving, and to assure adequate body weight, frame size and body condition score (body tissue reserves) at calving for greater average productive lifetime.

The first specific objective is to assess the average GGAVATT-Tepetzintla replacement herd scenario. Parameters include the predictions of nutrient requirements throughout early life for management groups of animals born in different forage seasons of the year. This requires the determination of average daily body weight gain and dietary nutrient balances in growing animals based on physiological stages of growth and predicted nutrient intakes from typical diets comprising grass and supplement. This assessment will identify the main constraints on growth and development of heifers in the target herd scenarios.

The second specific objective is to analyze the impact of forage and other dietary substitutions on the expected growth and reproductive performance of replacement heifers. It is important to identify alternative local forage species (i.e., *Leucaena leucocephala*, *Gliricidia sepium*), improved forage cultivars (i.e., cv. Mulato, Tanzania) and harvested grasses (i.e., *Saccharum officinarum*, maize) in order to organize a forage portfolio and develop a management strategy by physiological stage and season of the year to achieve more rapid heifer growth.

The third specific objective is to increase the average daily weight gain of replacement females in order to achieve a younger AFC with desired BCS. Body weight losses should be minimized during the most critical seasons. Moreover, opportunity windows, in which the average growth rate can be increased by exploiting compensatory growth, should be identified. The increase in heifer growth rates reduces the age at calving by accelerating their maturation, but the proposed management system could increase rearing costs. The implications of reducing AFC will be assessed using a partial budgeting analysis to identify and understand the associated economic returns. This method will be used to evaluate economic returns associated with alternative management scenarios (diets) to achieve the target weight at earlier ages of first calving in replacement animals.

4.0 Materials and Methods

The target population of GGAVATT-Tepetzintla cattle herds is located in the municipality of the same name in the Low Huasteca region of Veracruz. Most farm families in this municipality are dedicated to livestock production with DP cattle systems. Tepetzintla is located at 21°10' N and 97°51' W at an altitude ranging from 60 to 1100 meters above sea level (masl), averaging about 260 masl. The landscape varies in slope from 0% to gradients of more than 30%. Most herds graze paddocks with slopes from 5 to 25%. The climate is warm-humid tropical [Am (f) in Köppen's classification] with an average annual temperature near 23 °C and average rainfall of about 1300 mm (Appendices 6 and 7). Figure 5 illustrates the average monthly rainfall and temperatures for the 30-yr period ending in 2000. Most rainfall occurs from June to October.

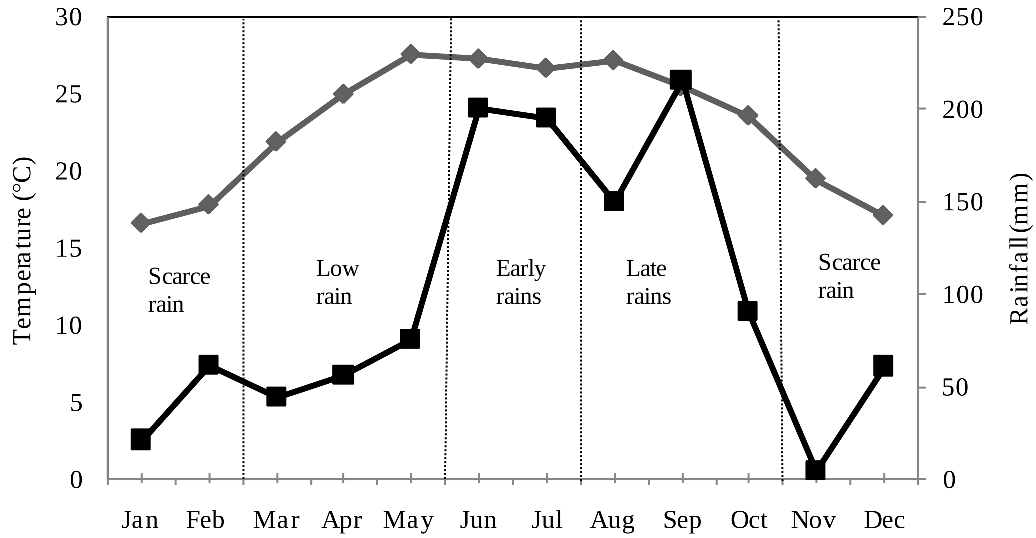


Figure 5. Mean monthly rainfall (mm, ■) and temperature (°C, ♦) in the warm-humid climatic zone of the municipality of Tepetzintla, Veracruz, from 1971 to 2000 (Estación meteorológica no. 3026, Tlacolula ETA 175, Comisión Nacional del Agua).

Information about typical animal husbandry, input use, animal productivity and farmer's objectives was obtained from annual reports GGAVATT-Tepetzintla (economic and technical evaluations) from 2002 to 2007 (Chagoya-Fuentes et al., 2002; González-Ortega et al., 2004; 2005; 2006; 2007; González-Ortega et al., 2003). Supplementary information about the strengths, weaknesses and objectives of GGAVATT-Tepetzintla was obtained from an INIFAP publication, Contribuciones del modelo GGAVATT al desarrollo de la ganadería: Testimonios (INIFAP, 2005). Information describing the management and inputs utilized by non-GGAVATT herds, especially in raising replacement heifers, was obtained from literature about cattle management in the tropical Gulf coastal region of Mexico (Magaña-Monforte et al., 2006; Osorio-Arce and Segura-Correa, 2008; Román-Ponce, 1981).

4.1 Definitions of feedstuffs and heifer management in GGAVATT-Tepetzintla

4.1.1 Feedstuffs utilized in GGAVATT-Tepetzintla

The forage inventories on member farms of GGAVATT-Tepetzintla are limited. Table 2 depicts the existing grass portfolio, in which the main species are Guinea grass (*Panicum maximum* var. Guinea) and African star grass (Cy*nodon plectostachyus*). These two species, representing about 80% of the total grass inventory, are the primary feeds for growing heifers on all farms in the region.

Table 2. Principal grass species on the 12 member farms of GGAVATT-Tepetzintla (González-Ortega et al., 2007).

Species	Farm land area (%)
Guinea grass (*Panicum maximum var. Guinea*)	59
Star grass (Cy*nodon plectostachyus*)	24
Bermuda grass (*Cynodon dactylon*)	6
Taiwan grass (*Pennisetum purpureum*)	4
Santo Domingo grass (*Paspalum notatum*)	2
Brachiaria hybrids (cv. Mulato I and II)	1
Maize (*Zea mays* spp.)	1
King grass (*Pennisetum purpureum* hybrid)	<1
Sugar cane (*Saccharum officinarum*)	<1

In recent years, GAVVATT Tepetzintla farms have been steadily replacing African star and Guinea grasses with improved cultivars (i.e., *Brachiaria* hybrids cv. mulato, Tanzania, among others) or harvested forages (i.e., sugar cane, *Pennisetum purpureum* spp., maize). The adoption of practices such as conservation, storage and cropping of feedstuffs for feeding cattle has been successful in these farms. Currently, the grass inventory utilized (Table 2) indicates that approximately 6% of farm land (~60 ha) is devoted to harvested forage crops like sugarcane (*Saccharum officinarum*) and Taiwan or King grass (*Pennisetum purpureum* spp.), and maize for ensiling (*Zea* *mays* spp.). These species are mainly used when pastures supplies are scarce (i.e., scarce and low rain seasons; Figure 6).

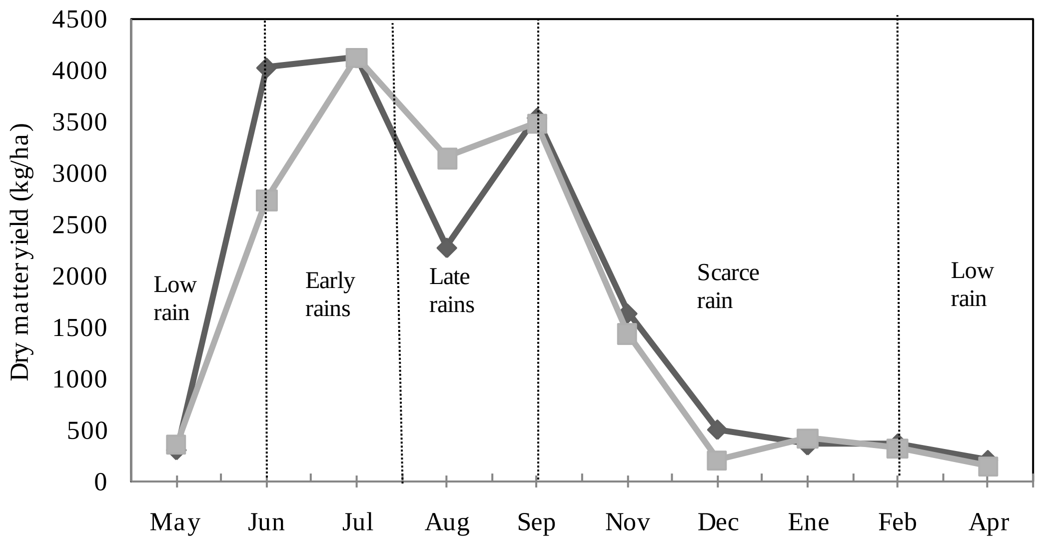


Figure 6. Average dry matter yields of *Panicum maximum* (♦) and *Cynodon plectostachyus* (■) harvested at 35 days of age from May 15, 2007, to June 19, 2008. Forages cropped at Campo Experimental "La Posta", Paso del Toro, Veracruz, México. The climate is warm-subhumid (Aw_1 Köppen's classification) with maximum and minimum temperatures from 31 °C to 19 °C, respectively, and annual rainfall of about 1300 mm (Montero-Lagunes, unpublished data).

4.1.2 Heifer management in GGAVATT-Tepetzintla herds

Replacement heifers in GGAVATT-Tepetzintla herds are raised artificially. After nursing their dams for the first two or three days of life, newborns are separated and fed 5 or 6 kg of milk replacer daily, until three months of age. At two months calves begin to receive a commercial concentrate and are sent to graze nearby paddocks of Africa star grass or Guinea grass. Once weaned, their diets consist of grazed forage plus about 0.5 kg/d of commercial concentrate until 6 mo and 1.0 kg/d of concentrate from 6 to 10 mo of age. Groups of heifers from three to ten months of age rotationally graze nearby paddocks. At about ten months of age, heifers are typically sent to distant locations to graze with older heifers and dry cows. Generally, these paddocks contain seasonal grasses, whose quality and quantity (Figure 6) vary seasonally with rainfall. Heifers are corralled monthly for pregnancy diagnosis and to identify animals that are close to parturition. Heifers at about one month before parturition are returned to graze on the main farm facility, where they receive a supplement of about 1.5 kg/d of commercial concentrate until calving.

4.2 Assumptions about dietary chemical composition and heifer management groups

4.2.1 Chemical composition of baseline diets in GGAVATT-Tepetzintla herds

Little information is available on forage chemical composition in the low Huasteca. Laboratory facilities are scarce and analyses are costly. For this study it was assumed that because temperature and rainfall patterns are similar the probable quality range throughout the year for the chemical composition of grasses in northern Veracruz is like that of pastures grown in central Veracruz[11]. Two sources of data provided the chemical compositions for forage qualities assumed in this study. Juarez et al. (2002) analyzed nutrient fractions from whole plants with harvest ages of 21, 28, 35, 42, 49, 56 and 63 days of regrowth. Montero-Lagunes (personal communication, 2008) analyzed probable grazed plant parts, mainly leaves and green stems, harvested at intervals of 35 days of regrowth throughout the year (from May 15, 2007 to June 19, 2008).

The quality of grazed forage for replacement heifers varied with rainfall in four grazing seasons of the year. The highest quality forage corresponded to the season of early rain (June 1 to July 30), when vegetatively young plants emerge and re-grow

[11] Campo Experimental "La Posta" de Paso del Toro, Veracruz, México. The climate is warm-subhumid (Aw_1 Köppen's classification). The maximum and minimum temperatures are about 31 °C and 19 °C, respectively. Annual rainfall is about 1300 mm, mainly occurring during the months from June to November.

after a long dry season. The season of late rain (August 1 to October 31) receives the highest rainfall, which results in rapid plant growth and accumulation of large quantities of biomass. During this time, forage quality declines with senescence. The season of scarce rain (November 1 through February) results in slower forage growth and older plants than in previous seasons, which yields a biomass of mediocre quality. In the dry season (March 1 through May) mature plants have the least feeding quality and biomass availability.

The assumed forage chemical compositions across seasons in this study corresponded to the average quality of different seasons of the year (Table 3). For the season of early rains, chemical composition corresponded to the months of June and July; for the late rain season, the forage quality corresponded to the average of plants grazed in August, September and October (Montero-Lagunés, unpublished data). For the dry period of the year (seasons of scarce and low rain), forage chemical composition corresponded to plants harvested at 42 to 49 days of re-growth, respectively (Juárez, et al., 2002).

The composition of the baseline forage diet for each of the grazing seasons was assumed to have a proportion of Guinea to African star grass similar to the one reported in the forage inventory of GGAVATT-Tepetzintla (Table 2). This proportion was 7:3, where 70% of the dry matter intake (DMI) in the diet was Guinea grass and 30% was African star grass. The chemical composition for each grass appears in Table 3.

The assumed commercial concentrate is the one that GGAVATT-Tepetzintla farmers typically use to supplement diets of milking cows. It was assumed to have a chemical composition like the one used in Central Veracruz (Absalon-Medina, 2008). Table 3 shows the chemical composition of this dietary supplement.

Table 3. Chemical composition[a] and predicted[b] contents of metabolizable energy and protein of forages and commercial concentrate typically utilized by GGAVATT Tepetzintla members to rear heifers.

Variable	Guinea grass[c] (*Panicum maximum var. Guinea*)				Star grass (*Cynodon plectostachyus*)				Commercial concentrate[h]
	Early rain[d]	Late rain[e]	Scarce rain[f]	Low rain[g]	Early rain[d]	Late rain[e]	Scarce rain[f]	Low rain[g]	
% DM[i]	19.0	19.6	35.1	37.0	25.3	25.7	38.7	40.4	92.9
CP[j], % of DM	9.8	7.1	6.6	6.6	12.4	10.2	7.6	6.5	17.0
SP[k], % of CP	28.9	34.4	39.7	21.3	30.0	18.1	48.4	23.2	26.1
NPN[l], % of SP	66.1	15.6	14.6	48.9	69.4	41.0	13.6	51.9	83.1
ADIP[m], % of CP	11.0	5.3	9.3	16.9	9.2	4.3	8.0	24.1	4.3
NDIP[n], % of CP	41.5	37.1	71.3	47.9	40.9	33.1	72.3	62.7	9.0
NFC[o],% of DM	8.2	7.6	14.0	10.7	6.3	7.2	5.5	4.8	56.6
ADF[p], % of DM	42.2	43.1	40.6	39.5	37.2	38.0	37.5	39.8	4.9
NDF[q], % of DM	67.5	70.7	64.9	66.5	69.5	72.2	74.0	76.8	9.7
Lig[r], % of NDF	3.4	2.7	6.1	6.1	3.8	2.7	14.7	14.1	3.5
Ash[s], % of DM	11.6	12.2	10.9	12.9	9.0	8.6	9.5	8.8	9.8
EE[t], % of DM	2.9	2.4	3.6	3.3	2.8	1.8	3.4	3.2	6.8
ME[u], Mcal/kg of DM	2.3	2.1	2.2	2.0	2.2	2.1	1.6	1.6	3.0
MP[v], g/kg of DM	78.0	70.0	69	60	70.0	72.0	63.0	52.0	68.0

[a] The chemical composition of the grasses for the seasons of early and late rain were taken from the Montero-Lagunes (unpublished data) analysis and that of the seasons of scarce and low rain were taken from the Juárez, et al. (2002) study.

[b] Values predicted by CNCPS 6.1

[c] The chemical composition of *P. maximum* var. Guinea was assumed to be similar to that of *P. maximum* var. Mombasa (Juárez, personal communication).

[d] Chemical composition of grasses harvested at 35 days of age, in June and July (Montero-Lagunés, personal communication).

[e] Chemical composition of grasses harvested at 35 days of age, in August and September (Montero-Lagunés, personal communication).

[f] Chemical composition of grasses harvested at 42 days of age (Juárez et al., 2002).

[g] Chemical composition of grasses harvested at 49 days of age (Juárez et al., 2002).

[h] The commercial concentrate consists of corn grain ground meal, soybean meal, molasses, urea, vitamins and minerals (Sample from GGAVATT Genesis, Absalon-Medina, 2008).

Table 3 (Continued)

[i] Percentage of dry matter
[j] Percentage of crude protein in dry matter
[k] Percentage of soluble protein in the crude protein
[l] Percentage of non-protein nitrogen in the soluble protein
[m] Percentage of acid detergent insoluble protein in the CP
[n] Percentage of neutral detergent insoluble protein in the CP
[o] Percentage of non-fibrous carbohydrate in the DM
[p] Percentage of acid detergent fiber in the DM
[q] Percentage of neutral detergent fiber in the DM
[r] Percentage of lignin in the DM
[s] Percentage of ash in the DM
[t] Percentage of ether extract in the DM
[u] Metabolizable energy, megacalories per kg of DM
[v] Metabolizable protein, grams per kg of DM

4.2.2 Chemical composition of alternative diets chosen for GGAVATT-Tepetzintla heifers

To accelerate heifer growth, alternative forages were chosen from the portfolio (Table 2) of improved grasses used in GGAVATT-Tepetzintla. From these options, cv. Mulato was selected to evaluate the effect of improved average forage quality. The chemical compositions of this cultivar for each grazing season were derived from analyses by Montero-Lagunés (personal communication, 2008) and are given in Table 4.

Other feed resources selected to complement the forage quality during the most critical seasons (scarce and low rain) included sugar cane and legumes, which have been recommended in the GGAVATT methodology. Sugar cane was chosen to support the diet during the dry season. The chemical composition (Juárez, personal communication) of this feedstuff was obtained from analyses of plant samples from Córdoba, Veracruz[12] (Table 4). Some protein fractions (SP, NPN, ADIP and NDIP) and the ether extract (EE) from this analysis were complemented by the database in the CNCPS library. Tropical grasses, however, may be low in protein content, especially during the season of low rain, which arrests animal performance. Therefore, alternative sources of available protein such as legumes could improve the growth of heifers reared in the tropics. The legume *Leucaena leucocephala*, which grows naturally in Tepetzintla, was chosen for this study to evaluate the benefits of extra protein in the diets of young animals. The chemical composition of this legume (Juárez-Lagunes et al., 2002b) corresponds to an average plant age of 62 days (Table 4). An alternative energy supplement was sorghum grain, which was chosen to

[12] Córdoba is located in the center of the state of Veracruz, at an elevation of 817 masl. Its climate is warm and humid, with an annual average temperature of 19.8°C. There is abundant rainfall in summer and autumn (1800 mm), with little rain in winter.

Table 4. Chemical composition[a] and predicted[b] metabolizable protein and metabolizable energy contents of alternative diets for rearing heifers in GGAVATT Tepetzintla

Variable	Mulato (*Brachiaria* hybrid)				Other feed supplements			
	Early rains[c]	Late rains[d]	Scarce rain[e]	Low rain[f]	*Leucaena leucocephala* [g]	Sugar cane[h] (*Saccharum officinarum*)	Sorghum grain[i]	Citrus pulp[i]
% DM	19.0	19.1	25.9	34.6	25.0	28.0	87.4	88.6
CP (% of DM)	12.2	9.2	8.5	4.4	26.4	1.9	10.4	6.9
SP (% of CP)	35.6	20.3	21.8	25.9	21.2	55.0	14.9	35.7
NPN (% of SP)	71.6	20.6	20.9	47.7	80.1	65.0	33.0	40.0
ADIP (% of CP)	9.4	11.9	13.0	18.2	13.1	9.0	5.0	10.2
NDIP (% of CP)	17.2	21.4	32.1	41.1	52.1	16.0	33.9	40.0
NFC (% of DM)	15.7	16.2	18.1	25.4	24.7	52.6	72.7	59.7
ADF (% of DM)	33.6	34.1	32.0	29.2	13.5	25.4	0.0	19.9
NDF (% of DM)	57.7	62.1	58.4	56.8	39.6	42.1	10.3	23.9
Lig (% of NDF)	2.8	2.6	1.9	3.6	7.7	4.5	12.8	9.8
Ash (% of DM)	11.2	10.8	11.6	10.4	6.7	2.0	3.0	6.35
EE (% of DM)	3.2	1.7	3.4	3.0	2.6	1.4	3.6	3.1
ME, Mcal/kg of DM	2.5	2.2	2.3	2.0	2.7	2.4	3.0	2.1
MP, g/kg of DM	84.0	77.0	73.0	45.0	115.0	23.0	91.0	73.0

[a] From Montero-Lagunes et al. (2008; unpublished data)
[b] Predicted by CNCPS 6.1
[c] Average chemical composition of grasses harvested from June to July
[d] Average chemical composition of grasses harvested from August to October
[e] Average chemical composition of grasses harvested from November to February
[f] Average chemical composition of grasses harvested from March to May
[g] The age of cutting was at 62 days of plant re-growth.
[h] Sugar cane composition based on analysis done in Córdoba, Veracruz, (Juarez, personal communication) and complemented with the CNCPS library.
[i] CNCPS version 6.1 tropical feed library

compensate for dietary deficiencies in critical seasons, especially when the dietary energy content drops below maintenance requirements. The chemical composition of this supplement was obtained from the CNCPS tropical feed library (Table 4). Other byproducts may also be used to compensate forage dietary energy deficits. Dried citrus pulp is an option because this byproduct is readily available during the season of low rain.

4.2.3 Management groups and assumptions about heifers

Seasons-of-birth for groups of heifers were defined using an approach similar to that in previous studies simulating nutrient requirements for beef and DP cows (Baba, 2007; Absalon-Medina, 2008). These birth seasons corresponded to the onset of each of the four forage seasons of the year (Table 5). The assumptions used to specify heifer management groups and herd scenarios in this study resulted from field observations and the collective opinion of a panel of experts[13].

Table 5. Definitions of heifer management groups by forage season of birth and stage of development in Tepetzintla herds.

Forage season of birth	Minimum	Maximum
Early rain	June 1	July 31
Late rain	August 1	October 31
Scarce rain	November 1	February 28
Low rain	March 1	May 31

Stage of development[a]	Age (mo)
Weaning	3
Puberty	21
Conception	28
Calving	37

[a] GGAVATT Tepetzintla, personal communication

[13] Panel of experts: Dr. Francisco Juarez-Lagunes and Dr. Ruben Loeza-Limon (professors at the Universidad Veracruzana (UV)); Dr. Bertha Rueda-Maldonado and Dr. Heriberto Roman-Ponce (researchers at the INIFAP); and Dr. Robert Blake and Dr. Michel Van Amburgh (professors at Cornell University)

Nutrient requirements and feed intakes vary with body weight, physical activity, physiological status, and phase of development (Fox et al., 2004). The average age of heifers in each phase of development, reported by GGAVATT-Tepetzintla farmers, is shown in Table 5. Management groups were defined by physiological stages of development: prepuberty (weaning to puberty); postpuberty (puberty to conception); and pregnancy (conception to calving). Table 6 shows the expected BW of heifers by physiological stage of development. Average BW utilized in this study corresponded to those expressed by GGAVATT-Tepetzintla farmers. Each expected average body weight by physiological stage of development and forage season of birth were then reviewed for logical consistency (plausibility) by the panel of experts.

Table 6. Body weights of heifers by stage of physiological development for replacement herds reared in GGAVATT-Tepetzintla and non-GGAVATT farms.

Physiological stage	Body weight (kg)	
	GGAVATT [a]	non-GGAVATT [b]
Weaning [c]	95	110
Puberty [d]	280	280
Conception [e]	380	380
Calving [h]	450	425

[a] GGAVATT Tepetzintla personal communication
[b] Non-GGAVATT body weights by physiological stages specified from reports on Mexican tropical livestock (Castañeda, 2003; Córdova-Izquierdo and Pérez-Gutiérrez, 2002; Román-Ponce, 1981)
[c] Body weight for weaned animals reported by farmers in GGAVATT Tepetzintla. For non-GGAVATT farms, the weaning age varies. Weaning age and weight chosen in this study for non-GGAVATT heifers were 4 mo and 110 kg of BW, respectively
[d] Puberty assumed to occur at 50% of mature body weight
[e] Conception assumed to occur when animals have reached about 70% of mature body weight

4.3 Cornell Net Carbohydrate and Protein System version 6.1

The information obtained from GGAVATT-Tepetzintla farmers, the panel of experts and available literature was used to define simulation cases for evaluation using the Cornell Net Carbohydrate and Protein System version 6.1 model (CNCPS v6.1) to predict growth rates, probable ME and MP requirements, probable feed intakes, nutrient requirements (maintenance, gain and pregnancy), and dietary nutrient balances for each management group of heifers. The simulations corresponded to combinations of four forage seasons of birth and three physiological stages of development (i.e., prepuberty, postpuberty and gestation) for representative GGAVATT and non-GGAVATT herds. These physiological stages of development were further sub-divided into a continuous array of shorter time segments, which were correlated with the lengths of respective grazing seasons. The number of grazing seasons per physiological stage varied with the average daily gain. Simulation scenarios included other inputs, such as physical activity and climatic conditions to accurately estimate differences in maintenance requirements by season of the year. These variables were specified for each physiological stage and forage season of the year (described in the next section). Some outputs, like BW losses, were calculated in accordance with CNCPS-predicted dietary energy balances.

4.4 Sensitivity and validation of the CNCPS model

A sensitivity analysis of the variations in climate conditions and the heifers' physical activity was conducted to determine the effects on total energy requirements for maintenance and dry matter intake. Three groups of heifers weighing 200, 300 and 400 kg were evaluated in two contrasting seasons of the year: early rains and scarce rain. First, basal energy for maintenance was determined assuming an animal in a thermo-neutral environment with little or no physical activity, and then each variable was altered (climate and physical activity) from lowest to highest (Appendix 8). Output changes were obtained for each increment in the input value, which was divided by the change in input to obtain an indicator of change. A value of zero indicates nil sensitivity of energy for the maintenance of that variable under the specified rearing conditions.

4.5. Predicted feed and nutrient intakes

Based on specified BW, daily activity, climatic conditions, and forage digestibility, the CNCPS-predictions were obtained for the mean voluntary feed intake for each time-growth segment of all management groups of heifers. The output obtained for each time-growth segment was used to approximate the total average daily feed intake. Because GGAVATT members feed fixed amounts of supplements during early prepuberty (from 3 to 10 mo of age), these quantities were used to predict the additional forage feed intake. For animals in the final month of gestation, the supplementation with commercial concentrate was additional to the total CNCPS-predicted forage DMI (Juárez, unpublished data).

Forage allocations during each physiological stage of development were arrayed in time segments, which were correlated with the lengths of the respective grazing seasons. Full appetite expression, or 100% *ad libitum* dry matter intake, of the CNCPS-predicted DMI (kg/d), was expected during the rainy time of the year (early and late rain seasons) and at the beginning of the dry season (scarce rain season). However, feed intake restrictions were assumed to occur in the second part of the dry season (season of low rain). During this period, DMI was to be about 90% of *ad-libitum* predictions. Estimations were based on monthly forage average DM yield (Figure 6), DMI (10.5 kg/d) per animal unit (AU = 450 kg), stocking rate used in GGAVATT-Tepetzintla (0.8 AU/ha) and assumed animal grazing selection (proportion of the plant grazed; 80%). Grazing selection was assumed to be the same proportion of the plant at 49 days of cutting, as was the case in Juarez et al. (2002).

4.5.1 Feed intake in non-GGAVATT herds

Except for the first 10 months of life, heifers in GGAVATT and non-GGAVATT farms of Tepetzintla are raised similarly. During the first ten months, GGAVATT farmers usually provide dietary supplementation for heifers in prepubertal stages, while non-GGAVATT farmers provide restricted amounts of milk (residual milk in the udder). Both systems rely on grazing.

Under traditional rearing, calves are usually with their dams during milking time and permitted to suckle either a whole quarter or the residual milk from all quarters. In the afternoon, they are separated from the cows and enclosed until the next day with little access to water and forage. They are raised in this manner until weaning at about 10 mo of age. Once weaned, they are sent to distant paddocks with the dry cows, where they remain until parturition when they return to the main farm facility. During the entire rearing period from weaning to calving, replacement animals graze pastures, mostly African star or Guinea grass.

The procedures used for determining the diets for non-GGAVATT heifers were like those described for GGAVATT-Tepetzintla heifers. The only difference in the diet of non-GGAVATT heifers was that instead of receiving commercial concentrates as a basic ingredient during the first months after weaning (GGAVATT farms), 1.8 kg of cow’s milk was fixed in the baseline diet simulations from 4 to 10 mo of age (weaning age).

4.6 Determination of maintenance requirements

The CNCPS model was used to predict ME and MP requirements, feed intake and nutrient dietary balances for all animal groups. The CNCPS model, comprising a linked set of sub-models, predicts nutrient requirements according to physiological functions: body maintenance, growth, pregnancy, lactation and body tissue reserves (Fox et al., 2004). The maintenance requirement, constituting the largest amount of energy expenditure for animals, is determined by metabolic body size, breed, physiological stage of development, nutritional status (e.g., BCS), physical activity, amount of urea excretion, acclimatization and effects of temperature stress (Fox et al., 2004; Tylutki et al., 2007).

The CNCPS model utilizes the following equation to determine the basal maintenance requirement in a thermal-neutral environment with minimal physical activity for a 3/4 *Bos taurus* and 1/4 *Bos indicus* crossbred: NEm (Mcal/d) = mean $BW^{0.75}$ × the proportional average requirements for fasting metabolism requirements of each breed computed (Fox and Tylutki., 1998). For pregnant animals, CNCPSv6 subtracts the conceptus weight from the shrunk body weight (SBW) to compute maintenance requirements (Tylutki et al., 2007).

The CNCPS model computes the cost of energy required to dissipate excess body heat (Fox et al., 2004) using the equations for the current effective temperature index (CETI) of Fox and Tylutki (1998). According to data from the Comisión Nacional del Agua (1971 to 2000) the maximum average monthly temperature and relative humidity reported in Tepetzintla were about 28°C and 80%, respectively. Based on the CETI, the daytime climatic effect for this study was in the range of caution (28°C to 32°C). The average temperatures by season of the year were 18°C during scarce rains (winter), 25°C during the low rain season, and about 27°C and 25°C during early and late rains, respectively. The highest monthly average nighttime temperature at our study site is about 22°C, which allows for dissipation of body heat accumulated during the day. Therefore, panting and heat stress were ignored in this study.

The CNCPS model adjusts for differences in physical activity based on the energy expenditures for the amount of time standing, the number of body position changes, and the distances walked daily on flat and sloped (hillside) surfaces (Fox et al., 2004; Fox and Tylutki, 1998). Tedeschi et al. (2004), Fox et al. (2004) and Brosh et al. (2006) provided guidelines for choosing these input values for animals managed in confinement and grazing conditions.

Young heifers (3-10 mo) on GGAVATT farms graze in rotational systems on paddocks close to the central facilities. The paddocks are flat with distances to water of about 300 m (GGAVATT, personal communication). The daily physical activities assumed for these animals were 14 h standing, 6 changes in body position, and about 1000 m walked. No differences in physical activity by season of the year were assumed for this group of animals. On the other hand, heifers from 10 mo of age until one month prior to parturition continuously graze sloped paddocks with maximum average distances to water of about 500 m (GGAVATT Tepetzintla, personal communication). Significant seasonal differences in energy requirements for physical activity, especially walking (Appendix 9), were specified in accordance with grass availability, ambient temperature and heifers' physiological status (Brosh et al., 2006). For example, non-pregnant heifers grazing during the rainy months (early and late rain seasons) were daily assumed to stand for 18 hr, change body position six times, and walk 200 m on sloped surfaces (10% of flat walked distances) and 1800 m on flat surfaces. Heifers in the final month of gestation are generally managed in paddocks next to the main facilities. Therefore, they were assumed to have movements similar to animals in a feedlot (3 to 5 m^2/animal), which corresponded to about 14 h standing, 6 position changes and about 500 m of flat distance walked per day.

4.7 Equations to estimate energy and protein requirements for growth of heifers

The CNCPS predicts energy and protein requirements for growth based on body weight, rate of body weight gain, chemical composition of gain, and mature weight (Tylutki et al., 2007). The equations used in the model (Table 4 of Fox et al., 2004) to predict nutrient requirements for different stages of growth are based on the shrunk body weight (SBW)[14]. The SBW of a mature DP cow of 550 kg is equal to 528 kg for a body condition score (BCS) of 3.0 on a scale of 1.0 to 5.0 units. Mature SBW is defined as the weight at which added body mass does not contain additional protein.

The net nutrient requirements for growth are estimated from the energy and protein content of the tissues deposited. Thus, the total amount of energy required for growth was calculated from the net energy deposited (NE_g), or retained energy (RE). The CNCPS model uses the equations of Garrett (1980), adjusted for mature size, to compute the energy content of tissue gains in different stages of growth and rates of gain. A size scaling system is used to adjust the SBW to a weight equivalent (EqSBW) to that of a standard reference animal at the same stage of growth (Eq.1; Tylutki et al., 2007), as follows:

$$EqSBW = SBW \times (SRW / AFBW) \qquad (1)$$

[14] The SBW is defined as 96% of the full body weight (FBW), which is equivalent to an animal's average BW expected after an overnight fast without water or feed. This proportional weight is used to compute net energy for maintenance requirements (NE_m), amount of net energy available for growth in the diet (NEg) and target shrunk weight gain (SWG). (Fox et al., 1999; 2004; NRC, 2001).

where SBW is 96% of the full body weight (FBW). Standard reference weight (SRW) is the mature SBW (478 kg for replacement heifers) of the standard reference animal and AFBW is the expected SBW at maturity (Fox et al., 2004; Tylutki et al., 2007).

CNCPSv6 utilizes Eq. 2 (Tylutki et al., 2007) to compute the SRW of growing and finishing cattle based on the final body fat (FBF) as recommended by the NRC (2000)

$$SRW = 399.9 - (1019.5 \times FBF) + (4621.1 \times FBF^2) \quad (2)$$

where FBF is the final body fat (kg/100 kg FBW).

The equivalent empty body weight (EqEBW) is 0.89 × equivalent shrunk body weight (EqSBW), and equivalent empty body gain (EqEBG) is 0.956 × shrunk body gain (SBG). These variables are used to predict required NE_g (Eq. 3) to formulate diets that support a target daily gain.

$$NE_g \text{ (Mcal / d)} = 0.0635 \times EqEBW^{0.75} \times EqEBG^{1.097} \quad (3)$$

To evaluate whether the current diet meets or exceeds the target daily gain, daily net energy available for growth (NE_g) from the diet after maintenance requirements are met is used along with the body weight adjusted to the weight of the standard reference animal to predict the daily gain the diet will allow. This relationship is shown in Eq. 4.

$SWG = 13.91 \times NE_g^{0.9116} \times EqSBW^{-0.06837}$……………………………………(4)

The net protein of gain is estimated according to the relationship between energy retained and protein content of gain. The protein content of SWG (net protein for gain, NP_g) is computed using Eq. 5.

NP_g (g/d) = SWG × (268 – (29.4 × (RE / SWG))……………..………………(5)

In addition, CNCPS v. 6.1 estimates requirements for metabolizable protein (MP) for mammary growth based on values reported by VandeHaar and Donkin (1999). This version, which computes MP for mammary growth using Eq. (6) instead of the fixed amount of 276.7 g/d (Fox et al., 2004), as in past CNCPS versions, allows a continuous calculation of MP required for mammary growth as EqSBW changes (Tylutki et al., 2007).

MP_{mm} = 80 / (0.834 – 0.00114 + EqSBW)…………………..………………..(6)

where MPmm is metabolizable protein for mammogenesis (g/d) and EqSBW is equivalent shrunk body weight (kg).

4.8 Determination of growth, energy balance and changes in body weights

Due to the lack of information on BW and BCS for heifers reared in tropical scenarios, probable growth performance for crossbred heifers in Tepetzintla herds was obtained based on personal observations by the twelve members of GGAVATT-

Tepetzintla and the collective experience of a panel of professionals in Mexico. These votes of perception were averaged for the key BW (Table 6) in each important physiological stage of animal development (Table 5). Each stage was then sub-divided into shorter time segments that intersected with grazing seasons of the year to accurately represent variations in nutrient requirements throughout rearing.

The CNCPS was used to compute probable growth rates of heifers during each time segment or grazing season with the "Use Period In/Out" function. This function predicts probable growth during a specified time period based on the following inputs: climatological conditions, physical activity, physiological status, nutrient intake and animal genotype. The "Period-In FBW" is the initial BW for each period in each simulation. The "Period-Out FBW" is calculated using the (CNCPS-predicted) inputted weight gain (kg/d), which was adjusted according to the nutrient most limiting for growth (i.e., energy[15] or protein allowable gain [kg/d]). For example, for heifers in GGAVATT Tepetzintla, the first period of growth in all the groups is 95 kg, which was the initial input for the Period-In FBW (Table 6). The predicted growth (average daily gain; ADG) or Period-Out FBW was then adjusted according to the inputted gain and energy or protein allowable gain, which was determined by the most limiting nutrient. To evaluate subsequent periods of growth, outputs from the Period-Out FBW were the initial inputs for the Period-In FBW, and then the predicted average daily gains (ADG) were adjusted for the allowable energy or protein for growth available from the diet. These procedures were repeated for each period until the probable date of calving (9 mo after achieving the typical BW at mating).

Dietary energy balances were determined using outputs from the CNCPS. The CNCPS has a series of sub-models that calculate the nutrient content (ME and MP) in

[15] The energy allowable gain is the remaining ME available after meeting the requirements for maintenance. This energy, which is CNCPS-predicted, is utilized by the animal for growth.

the diet, and the nutrient requirement (ME and MP) for maintenance according to the SBW of the animal and nutrient requirements for physiological status like growth, pregnancy or lactation. The dietary energy balance was calculated by subtracting the total energy required for maintenance from total intake.

Calculation of the amount of energy supplied from BW losses at a specific negative energy balance was determined according to the following assumptions. First, it was assumed that the ME to net energy (NE) conversion was 0.51% (0.0051) (Van Amburgh, personal communication). This proportion represented partial energy to maintenance and partial energy to pregnancy. Then, it was assumed that each kilogram of EBW tissue mobilized was worth 3.4 Mcal NE (Meyer, 2005), which were used at 80% of efficiency (NRC, 2001). For example, if heifers during the seventh and eighth months of pregnancy were 3.0 Mcal/d ME deficient, they would be 1.53 Mcal/d NE deficient. Then, for each kg of EBW mobilized, about 3.4 Mcal NE is yielded, but its use efficiency is just 80%, which means that there are only 2.72 Mcal NE available for pregnancy and maintenance. To determine how much body tissue was mobilized per day, the NE deficiency is divided by the NE mobilized and then multiplied by the number of days of negative energy balance. Thus, 1.53 Mcal/d divided by 2.87 Mcal/kg was equal to 0.53 kg/d of EBW tissue mobilized, which multiplied by the negative balance period results in 32.5 kg of EBW. Therefore, the total FBW catabolized during this period (61 d) of development was estimated to be about 38 kg.

4.9 Alternative diets to improve heifer growth

The baseline scenarios of heifer growth were used to identify nutritional bottlenecks in GGAVATT rearing systems. Based on these findings, dietary alternatives (Table 4) were explored to alleviate nutritional constraints and improve the growth of replacement females by achieving better frame sizes and earlier ages at first parturition. Interventions consisted of the incorporation of good quality diets, in which GGAVATT farmers already have invested, into the management protocol of heifers. These diets were hay from improved forages, sugarcane, legumes and sorghum, which will be used to attenuate the most limiting nutrient requirement.

4.10 Economic evaluation of rearing heifers

As in previous studies (Absalon-Medina, 2008; Rueda et al., 2003), the method of partial budgeting was used to evaluate the economic incentive to reduce AFC. The partial budgeting method helps to screen options to improve farm systems productivity. Although this method typically ignores the transition period for technology adoption and is limited to a specified range of options, partial budgeting helps to identify potentially economic alternatives and eliminate unprofitable ones (CIMMYT, 1988). Based on experience and empirical evidence, CIMMYT (1988) found that the adoption of technologies is more common when the marginal rate of return (MRR) is > 0.5, where the MRR = change in net margin/change in costs. For example, farmers would accept a new technology with at least MRR > 0.5 when they already have experience with it (i.e., improved forages, cropping forages and silages) and have made modest adjustments to their management practices (e.g., feed improved forages to replacement heifers). However, if the technology is new to the farmer (e.g., non-GGAVATT farmers) and requires the learning of new skills, the farmers may expect MRR > 1.

The economic effect of using better diets to reduce AFC was analyzed determining the marginal change in income over feed cost (ΔIOFC) for the alternative management compared to traditional practices. The ΔIOFC was estimated from the change in the present value of feed costs (ΔPVFC) through AFC and the difference in the present value of revenues from milk production (ΔPVM) at first and third lactations:

$\Delta IOFC = IOFC_A - IOFC_T$

where $IOFC_A$ = PV of Milk $Revenues_A$ – PV of Feed $Costs_A$

$IOFC_T$ = PV of Milk $Revenues_T$ – PV of Feed $Costs_T$

This evaluation did not include the cost of additional replacement heifers, milk yield over the animal’s life in the milking herd, nor any other changes in management or labor needs.

The change in feeding cost for rearing heifers until first parturition depends on the quantities of required feed inputs to obtain earlier AFC with alternative diets (i.e., hay from improved forages, leucaena, sorghum grain and sugarcane) compared to typical (baseline) performance for a specified management group of heifers. This analysis did not include cost changes for management labor, health or housing. Changes in feeding costs (ΔFC) at first calving for typical and alternative dietary management systems in the GGAVATT-Tepetzintla, was calculated as follows:

$$\Delta FC = \sum_{f} \sum_{t=0}^{AFC_A} FPD_{ft}^{A} \cdot CPF_{f}^{A} - \sum_{f} \sum_{t=0}^{AFC_T} FPD_{ft}^{T} \cdot CPF_{f}^{T}$$

where FPD_{ft} is the feed amount per day, CPF_f is the cost per unit for each feed, *t* indicates the month, the A subscript means the alternative feeding strategy and T means the typical feeding strategy.

The ΔPVFC to AFC was calculated for typical and alternative dietary management systems in the GGAVATT-Tepetzintla, as follows:

$$\Delta PVFC = PVFC_A - PVFC_T$$

where the present value for feeding costs was calculated using the following equation:

$$PVFC = \sum_f \sum_{t=0}^{AFC} \frac{FPD_{ft} \cdot CPF_f}{(1+i)^t}$$

where FPD_{ft} is the feed amount per day, CPF_f is the cost per unit for each feed, t indicates the time (months) and i is the discount rate.

To determine the effect that AFC at 30 and 38 mo had on cash flow, the present value approach was used to evaluate the increased gross income of first lactation milk sales and 3-lactation lifetime milk sales. Differences between PVs for milk sales (ΔPVM) in the traditional GGAVATT management and alternative management were calculated as follows:

$$\Delta PVM = PVM_A - PVM_T$$

where the present value of milk revenues was calculated using the following equation:

$$PVM = \sum_{t=0}^{Lact} \frac{Milk_t \cdot P_t^{Milk}}{(1+i)^t}$$

where t correspond to the month of lactation, $Milk_t$ is the amount of milk production at time t, $P_t^{Milk}$is the price of milk per kg at time t, *Lact* indicates the time through which milk values will be summed (i.e., 1st or 3rd lactation) and i is the discount rate. For this analysis, endpoints of first lactation and 3-lactation lifetime were used as the date of total milk sales (9 mo lactations). The interest rate used was 8%, based on the 7.91% interbank interest rate balance[16] in Mexico (tasa de interés interbancaria or TIIE) from February 27, 2009 to March 27, 2009 (Banco de México, 2009).

[16] TIIE is an interbank interest rate in Mexico, which is quoted from at least six banks, or credit institutions, utilized in the financial system (Diario Oficial de la Federación, 1995).

A group of cows (calving in early rains) from Absalon-Medina's study (2008) under baseline management was used as a reference to determine milk yield in first lactation and for a 3-lactation lifetime milk yield. Body weight and BCS at first calving were not used to measure milk yield responses, since cows that calve at 38 mo had lower BW and BCS than those calving at 30 mo; moreover, the grass season for heifers calving at 30 mo does not correspond to the early rain season assumed for this analysis. ΔPVM was determined assuming similar milk production in both cases, although heifers with better BCS and heavier BW are expected to have higher milk yield responses (Absalon-Medina, 2008). The ΔPVM did not include feeding cost during lactation nor labor, veterinary services, reproduction, and any other expense.

The prices of the feedstuffs (Table 7) used in the analysis were from March 2009, and were obtained from the local market and from estimations by GGAVATT-Tepetzintla producers. Supplements like commercial concentrates and sorghum are typically obtained from local suppliers. Mulato grasses, sugarcane and legumes are found in GGAVATT-Tepetzintla farms. An estimation of hay from improved grasses was assumed to be equal to the prices per kg for DM for *Brachiaria brizantha* grass hay in the local market. The price for seasonal grasses (African star and Guinea grass) was assumed to have the same price as for African star grass in the local market at Tepetzintla. Because hay prices may overstate the actual production cost for seasonal forages, a sensitivity analysis using 50% of the hay price as the cost of forage was also conducted. The valuation of milk sales in this study through the year was of $0.32/kg (Table 7).

Table 7. Market prices for milk and dietary inputs analyzed in this study ($/US[a]).

Feed	Price ($/kg DM)
Seasonal grasses[b] (increased price)	0.070
Seasonal grasses[c] (reduced price)	0.035
Legume[d]	0.150
Hay of improved forage (cv. Mulato)[e]	0.110
Sugarcane[f]	0.150
Sorghum[g]	0.260
Commercial concentrate[h]	0.310
Milk	0.320

[a]Average exchange rate in the second semester of 2008. $1 USD= $11.47 Mexican pesos (International Monetary Fund, 2009). Feed prices are expressed on a dry mater basis.
[b]Price of seasonal forages assumed to be equal to the local market price for hay of African star grass.
[c]50% of the hay price as the cost of seasonal forages
[d]*Leucaena leucocephala*;
[e]Price of hay of improved forage assumed to be equal to the local market price for hay of *Brachiaria brizantha*
[f]Approximate price of the on-ranch harvested sugarcane (GGAVATT-Tepetzintla, personal communication)
[g]Sorghum price in March 2009 (GGAVATT-Tepetzintla, personal communication).
[h]Commercial concentrate price in March 2009 (GGAVATT-Tepetzintla, personal communication).

5. Results and discussion

The following section reports and discusses findings from the predicted body weight gains under typical nutrition management, or baseline, protocols. Animal responses are organized sequentially by physiological stages of growth from weaning to calving for heifers born in alternative forage seasons of the year. Analyses show the predicted DMI (for each dietary ingredient), total daily intakes of ME and MP, body weights, daily nutrient requirements (maintenance, growth and pregnancy), the quantities of energy and protein that are available, or allowed, for growth, and the average daily feed nutrient balances (ME and MP) during sequenced rearing periods for heifers born at the onset of each forage season of the year.

Section 5.1 depicts how the range of expected fluctuations in physical activity and environmental factors may influence the predictions of energy for maintenance requirements and dry matter intake (DMI) of heifers in different seasons of the year. Section 5.2 reports the systematic evaluations of typical growth from weaning to calving for animals reared in GGAVATT-Tepetzintla herds. Factors considered were climatological conditions, nutrient intakes and physiological stages of development. In addition, section 5.3 summarizes growth and nutrient balances based on dietary intakes with a discussion of the key constraints affecting growth and, consequently, age at first calving.

5.1 Sensitivity analysis of the effects of variations in climatic conditions and physical activity on total energy requirements for maintenance and daily dry matter intake

Energy for maintenance of an animal is the amount of feed energy intake that results in neither net loss nor gain in energy in body tissues (NRC, 1996). This quantity is required for essential metabolic processes, body temperature regulation, and physical activity (Fox and Tylutki, 1998). Energy requirements for maintenance are affected by endogenous factors such as BW and physiological stage of development (e.g., tissue composition: Fox and Tylutki, 1998; Fox et al., 2004). Among the exogenous factors, variations in environmental conditions to which grazing animals are exposed often affect feeding behavior and, consequently, physical activity. In addition, factors such as season of the year, stocking rate, herbage quality, standing biomass, and terrain influence the amount of energy required for thermoregulation and physical activity (Fox and Tylutki, 1998; Brosh et al., 2006).

Correspondingly, a sensitivity analysis was conducted to identify changes in the amount of energy required for body maintenance for the expected range in environmental conditions and physical activity for heifers raised on the rangelands of Tepetzintla. Three groups of heifers, weighing 200, 300 and 400 kg, were evaluated in two contrasting seasons of the year: early rains and scarce rain. The factors measured and ranges in their differences between seasons are shown in Appendix 8.

Variations in maintenance requirements were especially associated with physical activity, especially the daily distance walked (flat and sloped). The sum of maximum differences for these variables resulted in about 0.4, 0.6 and 0.9 Mcal/d of ME for body maintenance of heifers older than 10 mo and weighing 200, 300 and 400 kg, respectively (Appendix 10). According to assumptions about distances walked in different seasons of the year, heifers grazing in the season of scarce rain would be expected to require 5% to 7% more energy for maintenance than their counterparts in the season of early rains.

Most combinations of climatic grazing conditions resulted in little discernible effect on the total maintenance requirement. Heifers were not predicted to encounter upper critical temperatures (e.g., panting; Fox and Tylutki, 1998), so increased energy to dissipate excess body heat was not expected. For the set of simulations in this study, the effective temperature index at the maximum temperature (27 °C) and relative humidity (78%), and wind speeds of 23 km/h were in the safe range (Fox and Tylutki, 1998). However, despite this, significant reductions in DMI were predicted when daylight temperature and minimum night temperature exceeded the thermoneutral temperature of 20 °C, conditions that are common in the season of early rains. Considerable depression in feed consumption was expected from increases in relative humidity and sun exposure, which were ameliorated by increases in wind speed. A reduction in DMI of ~1 kg/d was predicted when climatic conditions were more severe. In other words, the ADG for animals reared in the season of early rains might be somewhat inflated, if heifers were consuming the extra 2.3 Mcal ME and 78 g MP contained in a kilogram of DM, which is reduced due to prevalent climatic conditions during this season. This means that the interaction of temperature, humidity and sun exposure limit the intake of forages and the quantity of nutrients available for growth, even when forage quality is highest during the early rains.

5.2 Analysis of current management and heifer productivity outcomes in GGAVATT herds

The following sections contain results from the baseline simulation analysis of nutritional constraints identified for heifers born in each of four forage seasons of the year. The figures summarize expected BW, growth rates, energy supplied from diets and body tissues, and the feed nutrient status of heifers throughout sequential physiological stages of growth and development (and coinciding seasons of the year).

5.2.1 Season of early rains

Systematic evaluation for the heifers born in the season of early rains (June 1) is shown in Table 8. These heifers are generally weaned in the second month of late

Table 8. Heifers reared in GGAVATT-Tepetzintla herds born in the season of early rains (June 1) under typical nutrition management: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout physiological stages of development.

Item	Prepuberty							
	Supplementation				Grazing			
Forage season[a]	L	S	S	N	N	E	L	S
Heifer age, mo	3-5	5-6	6-9	9-10	10-12	12-14	14-17	17-18
Forage DMI, kg/d	2.7	3.1	3.1	3.2	4.6	5.4	6.9	7.5
Forage ME intake, Mcal/d	5.5	6.1	6.3	5.8	8.3	11.6	14.0	14.8
Forage MP intake, g/d	202.0	221.0	226.0	189.0	272.0	417.0	526.0	550.0
Supplement, kg/d	0.5	0.5	1.0	1.0	…	…	…	…
Total DMI[b], kg/d	3.2	3.6	4.1	4.2	4.6	5.4	6.9	7.5
Total dietary energy[c], Mcal ME/d	7.0	7.5	9.0	8.9	8.3	11.6	14.0	14.8
Total dietary protein[d], g MP/d	261.0	269.0	321.0	299.0	272.0	417.0	526.0	550.0
Initial BW, kg	95	125	136	178	188	189	223	272
Mean BW, kg	110	131	157	183	189	206	248	278
Final BW, kg	125	136	178	188	189	223	272	284
Maintenance requirements[e]								
Energy, Mcal ME/d	4.1	4.8	6.0	6.2	8.2	7.6	9.1	10.8
Protein, g MP/d	152.0	184.0	203.0	217.0	262.0	253.0	327.0	376.0
Nutrients available for growth[f]								
Energy, Mcal ME/d	2.1	2.0	2.6	2.1	0.1	4.0	4.9	3.9
Protein, g MP/d	146.0	112.0	134.0	97.0	5.0	162.0	158.0	117.0
Pregnancy requirements[g]								
Energy, Mcal ME/d	…	…	…	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…	…	…	…
Energy allowable gain[h], kg/d	0.64	0.48	0.50	0.37	0.02	0.53	0.51	0.37
Protein allowable gain[i], kg/d	0.48	0.36	0.44	0.31	0.03	0.54	0.64	0.55
Inputted gain[j], kg/d	0.48	0.36	0.44	0.31	0.02	0.53	0.51	0.37
Feed energy balance[k], Mcal ME/d	0.8	0.7	0.4	0.5	0.0	0.0	0.0	0.0
Required %	101.0	98.0	95.0	94.0	88.0	92.0	95.0	100.0
Feed protein balance[l], g MP/d	-50.0	-43.0	-33.0	-36.0	-17.0	-17.0	26.0	57.0
Required %	84.0	86.0	91.0	89.0	94.0	96.0	105.0	112.0

Table 8 (continued)

Item	Postpuberty				Gestation (trimesters)					
	Grazing				1	2			3	
Forage season[a]	S	N	E	L	S	S	N	N	E	E
Heifer age	17-21	21-24	24-26	26-29	29-32	32-33	33-35	35-36	36-37	37-38
Forage DMI, kg/d	7.9	6.7	7.6	9.2	9.8	10.2	8.3	8.2	8.6	6.2
Forage ME intake, Mcal/d	15.6	12.0	16.2	18.5	19.5	20.0	15.2	14.6	18.4	13.5
Forage MP intake, g/d	583.0	398.0	588.0	702.0	728.0	753.0	500.0	486.0	668.0	481.0
Supplement, kg/d	…	…	…	…	…	…	…	…	…	1.5
Total DMI[b], kg/d	7.9	6.7	7.6	9.2	9.8	10.2	8.3	8.2	8.6	7.7
Total dietary energy[c], Mcal ME/d	15.6	12.0	16.2	18.5	19.5	20.0	15.2	14.6	18.4	17.6
Total dietary protein[d], g MP/d	583.0	398.0	588.0	702.0	728.0	753.0	500.0	486.0	668.0	616.0
Initial BW, kg	284	318	308	339	384	417	427	412	395	400
Mean BW, kg	301	313	324	362	401	422	420	404	398	401
Final BW, kg	318	308	339	384	417	427	412	395	400	402
Maintenance requirements[e]										
Energy, Mcal ME/d	11.5	12.5	11.0	12.5	14.6	15.2	15.5	15.4	13.1	10.9
Protein, g MP/d	397.0	375.0	348.0	429.0	486.0	506.0	455.0	450.0	390.0	335.0
Nutrients available for growth[f]										
Energy, Mcal ME/d	4.0	0.0	5.2	6.0	4.8	4.4	0.0	0.0	1.8	0.4
Protein, g MP/d	114.0	0.0	155.0	153.0	117.0	107.0	0.0	0.0	58.0	19.0
Pregnancy requirements[g]										
Energy, Mcal ME/d	…	…	…	…	0.1	0.3	0.8	2.0	3.5	6.1
Protein, g MP/d	…	…	…	…	4.0	10.0	26.0	64.0	112.0	206.0
Energy allowable gain[h], kg/d	0.35	-0.11	0.49	0.47	0.34	0.31	-0.24	-0.59	0.16	0.06
Protein allowable gain[i], kg/d	0.58	0.00	0.75	0.84	0.66	0.69	0.00	0.00	0.48	0.21
Inputted gain[j], kg/d	0.35	-0.11	0.49	0.47	0.34	0.31	-0.24	-0.59	0.16	0.06
Feed energy balance[k], Mcal ME/d	0.0	-0.5	0.0	0.0	0.0	0.0	-1.1	-2.7	0.0	0.0
Required %	100.0	91.0	97.0	100.0	100.0	100.0	93.0	84.0	100.0	100.0
Feed protein balance[l], g MP/d	72.0	6.7.0	74.0	120.0	122.0	131.0	19.0	-26.0	109.0	51.0
Required %	114.0	102.0	114.0	121.0	120.0	121.0	104.0	95.0	119.0	109.0

[a] Length of grazing time that corresponds to the seasons of forage growth: early rains (E), late rains (L), scarce rain (S) and low rain (N).
[b] Total amount of dry matter intake from grazing forages and consuming commercial concentrates (when this applies).

Table 8 (continued)

[c] Energy supplied by the forage diet and commercial concentrates when they are used.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996).
[f] Amount of nutrients available from the diet after the maintenance requirements are covered.
[g] Nutrients required for gestation. Estimates of the energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth.
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth.
[j] Average daily gain adjusted to the energy allowable gain.
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value indicates a decline in the average growth rate during a stage of growth; the value represents the amount of ME needed from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).

rains (at three months of age) when they weighed 95 kg. From this juncture BW was evaluated until the time of expected calving. Figure 7 describes changes in BW over this period. Predicted average body weights at puberty, conception and calving were 284, 384, and 402 kg, which were expected to occur at 18, 29 and 38 mo of age. These results were consistent with those typically observed in GGAVATT-Tepetzintla herds (GGAVATT, personal communication). The graph clearly shows how growth is repeatedly arrested during dry seasons, especially during the low rain season when animals are 10 to 12, 21 to 24 and 33 to 38 months of age (Figure 7; shaded areas).

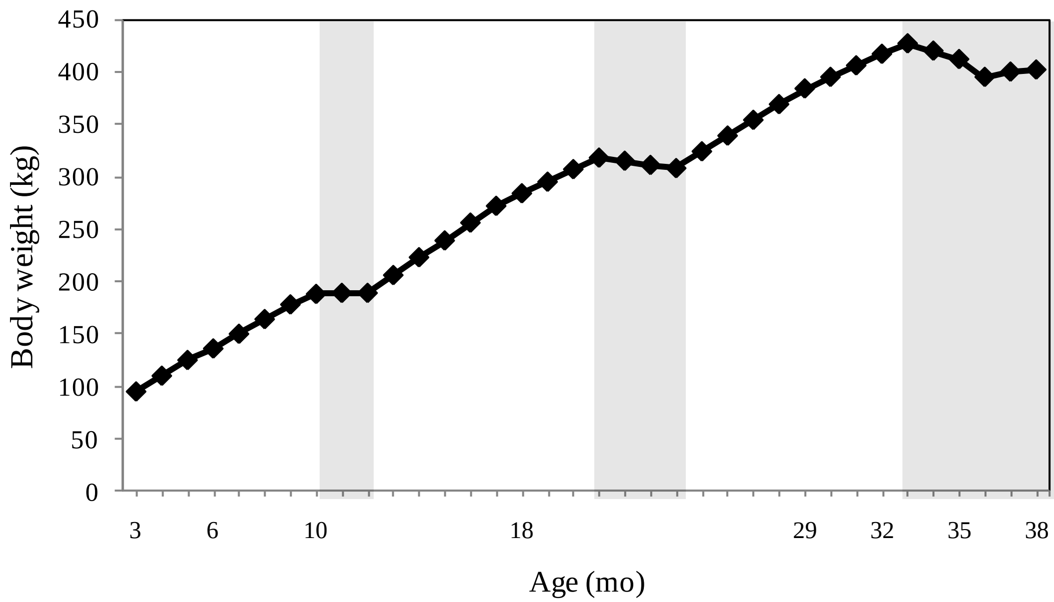


Figure 7. Predicted growth for heifers born at the onset of the early rains season (June 1). Shaded areas represent periods of nutrient scarcity and consequent constraints on growth.

Figure 8 shows the average daily gains for heifers born in the season of early rains. The ADG during the prepubertal stage was 0.41 kg/d, whereas predicted growth during postpuberty and gestation averaged 0.30 and 0.07 kg/d, respectively. The growth rate, affected by dietary outcomes throughout life, varied from a daily weight gain of about 0.53 kg/d with supplementation and rotational grazing to daily losses of -0.59 kg for pregnant heifers (seventh month of gestation) grazing continuously without supplementation.

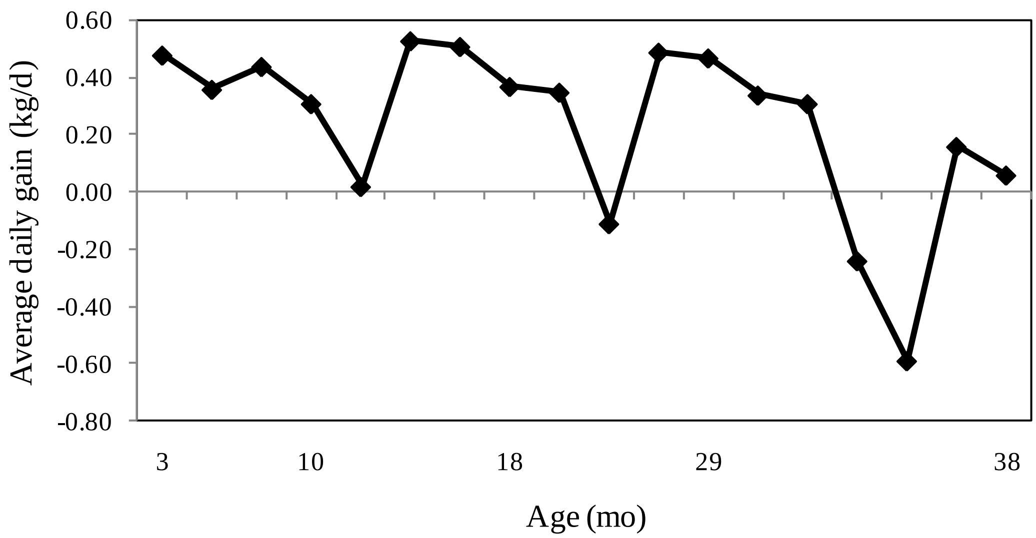


Figure 8. Predicted average daily gains for heifers born in the season of early rains (June 1).

Figure 9 describes seasonal (annual) variations in nutrient dietary balances from weaning to calving for heifers receiving typical GGAVATT-Tepetzintla dietary management. Dietary MP during the first stage of development, from 3 to 10 mo of age, was more limiting. MP balances ranged from 9% to 16% below requirements. After 10 mo of age, ME began to be the primary dietary constraint on growth. ME deficiencies were most severe during the season of low rain, resulting in tissue catabolism to support a shrinking maintenance requirement. In addition, negative energy balances were aggravated during the second and third trimesters of gestation, which corresponded to months with low rainfall when fetal requirements begin to increase exponentially, thus forcing heifers to sacrifice their own development and maternal tissues to support fetal growth (Figure 10).

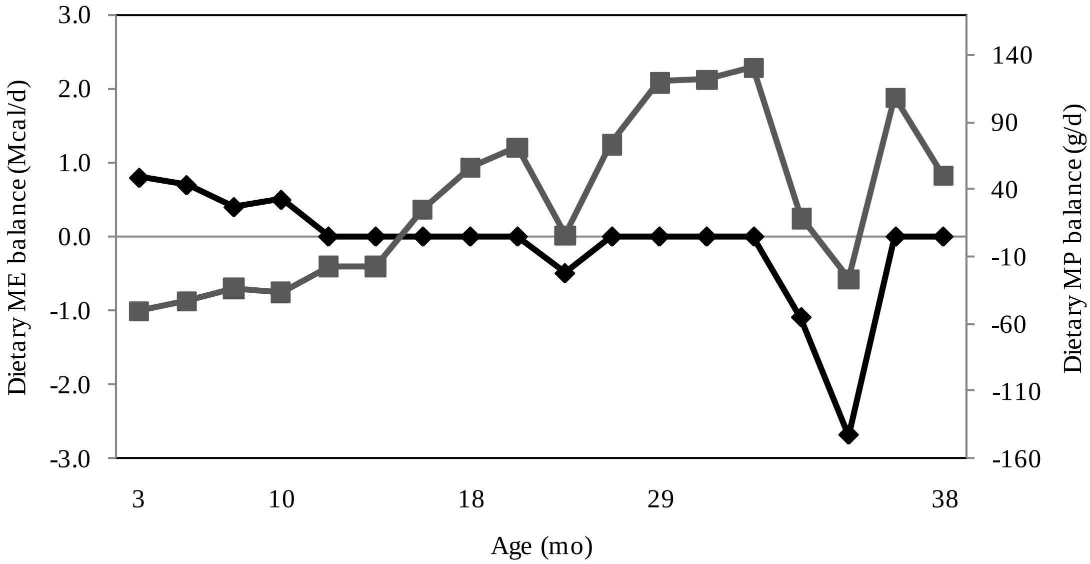


Figure 9. Predicted dietary balances of daily requirements for metabolizable energy (ME, ♦) and metabolizable protein (MP, ■) from weaning to first calving for heifers born in the season of early rains.

The predicted BW at calving for this group of heifers (402 kg) was 5% less than the weight of 426 kg (38 mo of age) assumed to be typical in GGAVATT-Genesis herds in central Veracruz (Absalon-Medina, 2008). GGAVATT-Genesis heifers are modestly supplemented during the dry season (length of time not specified), while GGAVATT-Tepetzintla heifers only received supplementation at the end of pregnancy. Consequently, heifers in this study were predicted to lose about 32 kg during the dry season (from the fifth to the seventh month of gestation) and were unable to fully recover lost tissue reserves. Despite supplementation and the good forage quality available during the final month of pregnancy, this group of animals was expected to weigh only 18 kg more than when they were bred. Avila (1995) reported similar stagnated growth during pregnancy in a DP herd (Brown Swiss or Holstein × Zebu) in Veracruz. In that study, the average weight at mating of Brown Swiss × Zebu heifers was 363 kg at 25 mo of age. However, the average weight at calving was 365 kg, which was about the same as at mating. This means that DP heifers grazing low quality forages are often forced to catabolize body tissues in late pregnancy (i.e., when fetal growth is rapid). The expected BCS at calving for these animals was about 2.25, which was inferior to the minimum recommended score of 3.0 (Fox et al., 2003). Therefore, mobilization and insufficient tissue reserves at calving are expected to restrict subsequent lactation performance and lifetime calf production (Deresz et al., 1987 cited by Villa-Godoy, unpublished; Vera et al., 1993).

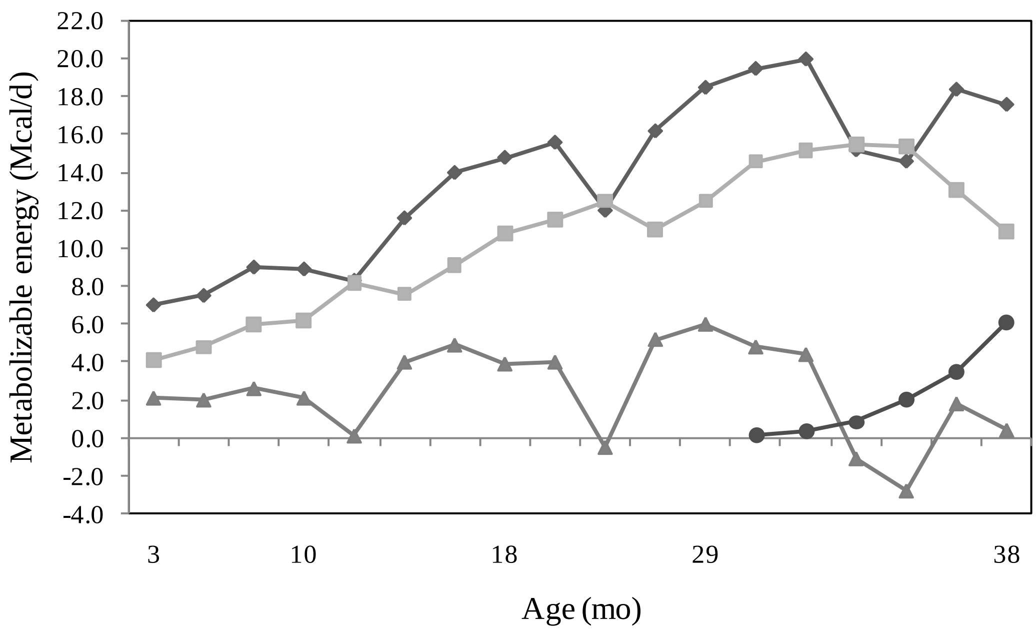


Figure 10. Feed energy intake (♦) partitioned among maintenance (■), growth (▲) and pregnancy (●) in different physiological stages of development in heifers born during the season of early rains (June 1).

5.2.2 Season of late rains

Heifers born in the season of late rains (August 1) are generally weaned in the season of scarce rain. Figure 11 shows growth from weaning to calving. Predicted body weights at puberty, conception and calving were 279, 383 and 417 kg, which were expected to occur at 17, 28 and 37 mo of age (Table 9). These outputs were similar to those reported by GGAVATT-Tepetzintla herd owners (GGAVATT, personal communication). Losses in BW are expected during the low rain season, when forage-based diets are not supplemented. These weight losses occurred at 19 to 22 and 31 to 37 months of age (Figure 11; shaded areas).

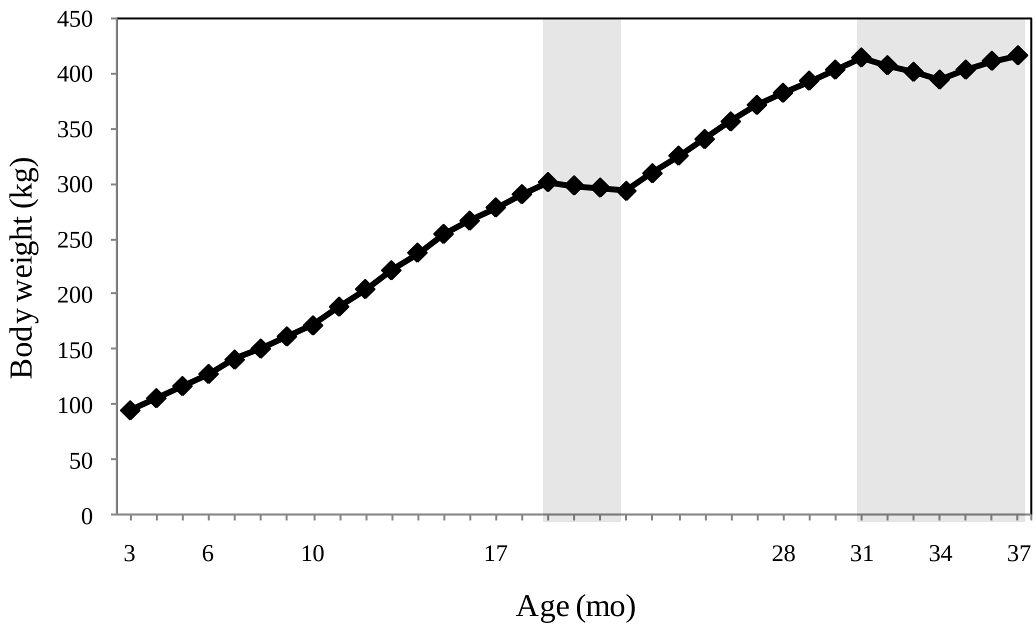


Figure 11. Predicted growth for heifers born at the onset of the late rain season (August 1). Shaded areas represent periods of nutrient scarcity and consequent constraints on growth.

Table 9. Heifers reared in GGAVATT-Tepetzintla herds born in the season of late rains (August 1) under typical nutrition management: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty					
	Supplementation			Grazing		
Forage season[a]	S	S	N	E	L	S
Heifer age	3-6	6-7	7-10	10-12	12-15	15-17
Forage DMI, kg/d	2.6	2.7	2.8	5.1	6.5	7.3
Forage ME intake, Mcal/d	5.3	5.4	5.1	10.9	13.3	14.3
Forage MP intake, g/d	191.0	196.0	165.0	391.0	498.0	533.0
Supplement, kg/d	0.5	1.0	1.0	…	…	…
Total DMI[b], kg/d	3.1	3.7	3.8	5.1	6.5	7.3
Total dietary energy[c], Mcal ME/d	6.6	8.2	8.1	10.9	13.3	14.3
Total dietary protein[d], g MP/d	238.0	290.0	272.0	391.0	498.0	533.0
Initial BW, kg	95	128	141	172	205	255
Mean BW, kg	112	135	157	189	230	267
Final BW, kg	128	141	172	205	255	279
Maintenance requirements[e]						
Energy, Mcal ME/d	4.3	5.4	5.5	7.2	8.6	10.5
Protein, g MP/d	163.0	183.0	196.0	238.0	310.0	365.0
Growth requirements[f]						
Energy, Mcal ME/d	1.6	2.2	1.9	3.7	4.7	3.8
Protein, g MP/d	106.0	130.0	100.0	159.0	161.0	117.0
Pregnancy requirements[g]						
Energy, Mcal ME/d	…	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…	…
Energy allowable gain[h], kg/d	0.49	0.52	0.43	0.52	0.52	0.37
Protein allowable gain[i], kg/d	0.34	0.43	0.32	0.52	0.60	0.53
Inputted gain[j], kg/d	0.34	0.43	0.32	0.52	0.52	0.37
Feed energy balance[k], Mcal ME/d	0.8	0.5	0.7	0.0	0.0	0.0
Required %	100.0	97.0	109.0	91.0	92.0	93.0
Feed protein balance[l], g MP/d	-44.0	-37.0	-24.0	-27.0	4.4.0	28.0
Required %	84.0	89.0	92.0	94.0	101.0	106.0

Table 9 (continued)

Item	Postpuberty					Gestation (trimester)			
	Grazing					1	2	3	
Forage season[a]	S	N	E	L	S	S	N	E	L
Heifer age	15-19	19-22	22-24	24-27	27-28	28-31	31-34	34-36	36-37
Forage DMI, kg/d	7.7	6.5	7.4	8.9	9.4	9.8	8.0	9.0	7.1
Forage ME intake, Mcal/d	15.2	11.6	15.8	18.0	18.5	19.2	14.6	19.2	14.5
Forage MP intake, g/d	568.0	384.0	573.0	683.0	695.0	722.0	481.0	699.0	539.0
Supplement, kg/d	…	…	…	…	…	…	…	…	1.5
Total DMI[b], kg/d	7.7	6.5	7.4	8.9	9.4	9.8	8.0	9.0	8.6
Total dietary energy[c], Mcal ME/d	15.2	11.6	15.8	18.0	18.5	19.2	14.6	19.2	19.1
Total dietary protein[d], g MP/d	568.0	384.0	573.0	683.0	695.0	722.0	481.0	699.0	707.0
Initial BW, kg	279	302	294	326	372	383	415	395	412
Mean BW, kg	291	298	310	349	378	399	405	404	415
Final BW, kg	302	294	326	372	383	415	395	412	417
Maintenance requirements[e]									
Energy, Mcal ME/d	11.2	12.0	10.6	12.1	14.0	14.6	15.1	13.2	11.6
Protein, g MP/d	388.0	362.0	339.0	418.0	469.0	486.0	440.0	406.0	371.0
Growth requirements[f]									
Energy, Mcal ME/d	4.0	0.0	5.2	5.9	4.5	4.6	0.0	3.2	1.4
Protein, g MP/d	116.0	0.0	159.0	153.0	113.0	112.0	0.0	94.0	48.0
Pregnancy requirements[g]									
Energy, Mcal ME/d	…	…	…	…	…	0.1	0.6	2.7	6.1
Protein, g MP/d	…	…	…	…	…	2.0	19.0	85.0	206.0
Energy allowable gain[h], kg/d	0.36	-0.09	0.50	0.47	0.34	0.33	-0.22	0.27	0.14
Protein allowable gain[i], kg/d	0.56	0.00	0.73	0.82	0.66	0.68	0.00	0.61	0.35
Inputted gain[j], kg/d	0.36	-0.09	0.50	0.48	0.34	0.33	-0.22	0.27	0.14
Feed energy balance[k], Mcal ME/d	0.0	-0.4	0.0	0.0	0.0	0.0	-1.0	0.0	0.0
Required %	100.0	90.0	95.0	97.0	98.0	100.0	93.0	97.0	95.0
Feed protein balance[l], g MP/d	65.0	3.6.0	59.0	100.0	106.0	121.0	22.0	98.0	55.0
Required %	113.0	101.0	111.0	117.0	118.0	120.0	105.0	116.0	108.0

[a] Length of grazing time that corresponds to the seasons of forage growth: early rains (E), late rains (L), scarce rain (S) and low rain (N).

[b] Total amount of dry matter intake from grazing forages and consuming commercial concentrates (when this applies).

Table 9 (continued)

[c] Energy supplied by the forage diet and commercial concentrates when they are used.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996).
[f] Amount of nutrients available from the diet after the maintenance requirements are covered.
[g] Nutrients required for gestation. The energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth.
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth.
[j] Average daily gain adjusted to the energy allowable gain.
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value indicates a decline in the average growth rate during a stage of growth; the value represents the amount of ME needed from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).

Figure 12 represents the average daily gains of heifers born in the late rain season. The prepubertal stage was characterized by growth rates that averaged about 0.43 kg/d, whereas the predicted growth during postpuberty and gestation averaged 0.31 and 0.12 kg/d, respectively. Average daily gains ranged from about 0.52 kg for prepubertal animals to body weight losses of -0.22 kg/d for pregnant heifers (second trimester), grazing continuously without supplementation.

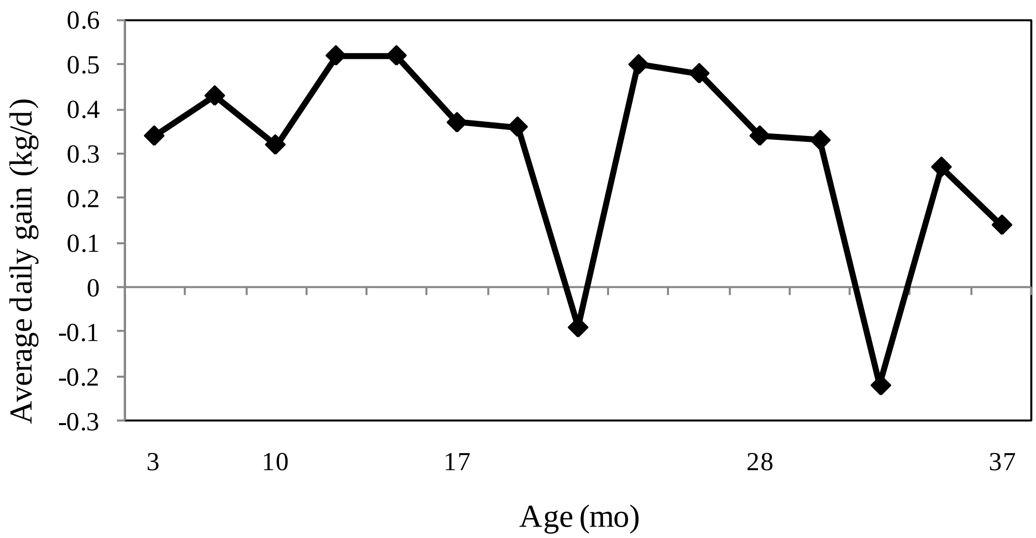


Figure 12. Predicted average daily gains for heifers born in the season of late rains (August 1).

Figure 13 shows seasonal dietary nutrient balances from weaning to calving for heifers receiving typical GGAVATT-Tepetzintla management. Dietary MP balances were most limiting during the initial months of development (from 3 to 10 mo of age), when deficiencies in MP ranged from 8% to 16% below the requirement for growth. In older animals, ME deficiencies were more significant. ME dietary deficiencies were greatest during the season of low rain, resulting in the mobilization of body tissues. Negative dietary ME balances were more evident during the second trimester of pregnancy (-1.0 Mcal ME/d) despite the low amount of energy required for fetal growth (0.6 Mcal ME/d). Figure 14 shows how the ME dietary intake is partitioned among maintenance, growth and pregnancy.

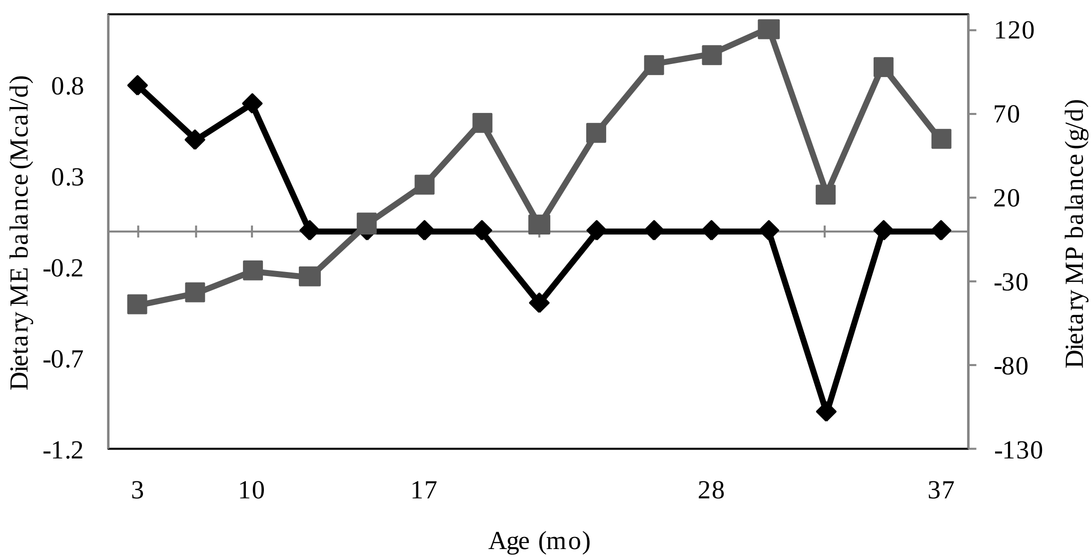


Figure 13. Predicted dietary balances of daily requirements for metabolizable energy (ME, ♦) and metabolizable protein (MP, ■) from weaning to first calving for heifers born in the season of late rains (August 1).

According to the evaluation, the ADG from weaning to calving was about 0.31 kg with a predicted BW of 417 kg and an age of 37 mo at calving. Body weight at calving was about 5% less than for heifers in GGAVATT-Genesis herds weighing 440 kg at 38 mo of age (Victor-Absalon, 2008). This difference in BW (23 kg) was about the amount of weight loss (20 kg) incurred by heifers during the second trimester of pregnancy (Table 9). Although the final trimester of gestation coincided with high quality forage in the rainy season, animals were able to regaining only what they had previously lost. At calving the BCS of these animals was about 2.50.

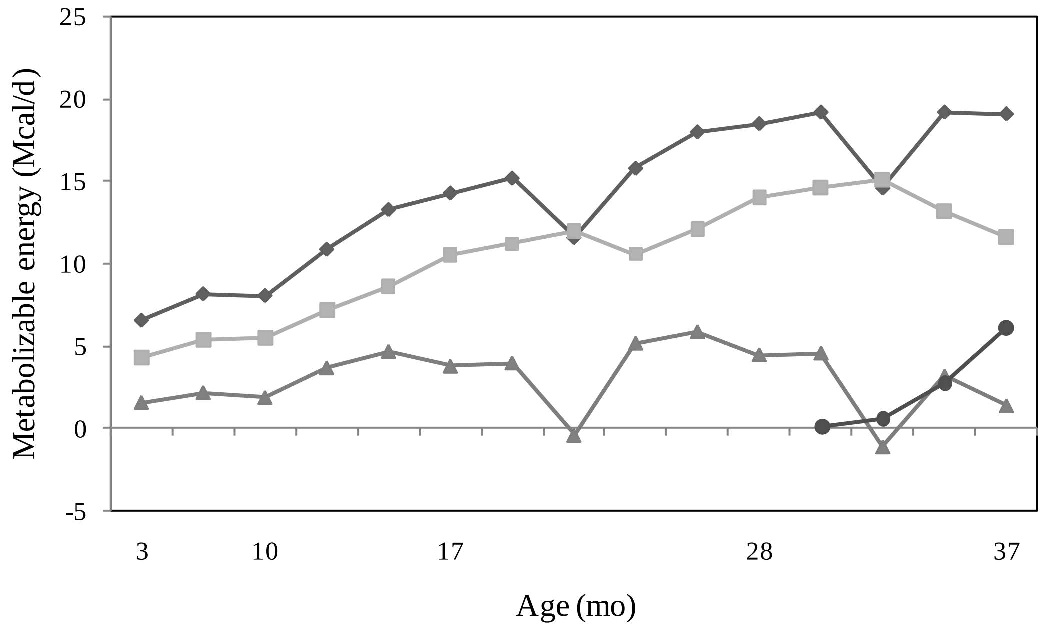


Figure 14. Feed energy intake (♦) and energy utilization for maintenance (■), growth (▲) and pregnancy (●) in different physiological stages of development in heifers born during the season of late rains (August 1).

5.2.3 Season of scarce rain

Heifers born at the onset of the scarce rain season (1 November) are generally weaned during the last month of the same season. The results of systematic evaluation of this group of heifers are shown in Table 10. Figure 15 describes changes in BW from weaning to first calving. Predicted body weights at puberty, conception and calving were 281, 381 and 426 kg, which were expected to occur at 20, 27 and 36 mo of age. These results were close to those typically observed in GGAVATT-Tepetzintla (GGAVATT, personal communication). The graph shows reduced BW gains from 16 to 19 and 28 to 31 mo of age, which corresponded to the season of low rain (Figure 15; shaded areas).

Table 10. Heifers reared in GGAVATT-Tepetzintla herds born in the season of scarce rain (November 1) under typical nutrition management: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty								
	Supplementation					Grazing			
Forage season[a]	S	N	N	E	L	L	S	N	E
Heifer age	3-4	4-6	6-7	7-9	9-10	10-12	12-16	16-19	19-20
Forage DMI, kg/d	2.5	2.3	2.1	2.6	3.5	5.9	6.7	5.9	7.5
Forage ME intake, Mcal/d	5.0	4.2	3.8	5.7	7.2	11.9	13.2	10.6	16.0
Forage MP intake, g/d	173.0	136.0	123.0	199.0	263.0	445.0	471.0	349.0	580.0
Supplement, kg/d	0.5	0.5	1.0	1.0	1.0	…	…	…	…
Total DMI[b], kg/d	3.0	2.8	3.1	3.6	4.5	5.9	6.7	5.9	7.5
Total dietary energy[c], Mcal ME/d	6.5	5.7	6.8	8.4	10.1	11.9	13.2	10.6	16.0
Total dietary protein[d], g MP/d	233.0	194.0	226.0	290.0	371.0	445.0	471.0	349.0	580.0
Initial BW, kg	95	107	119	129	162	181	215	265	261
Mean BW, kg	101	113	124	146	172	198	240	263	271
Final BW, kg	107	119	129	162	181	215	265	261	281
Maintenance requirements[e]									
Energy, Mcal ME/d	3.9	4.3	4.5	4.9	5.7	7.6	9.5	10.8	9.8
Protein, g MP/d	151.0	155.0	160.0	167.0	204.0	279.0	335.0	331.0	340.0
Growth requirements[f]									
Energy, Mcal ME/d	1.7	0.9	1.5	2.7	3.9	4.3	3.7	0.0	6.2
Protein, g MP/d	121.0	59.0	95.0	156.0	188.0	161.0	122.0	0.0	197.0
Pregnancy requirements[g]									
Energy, Mcal ME/d	…	…	…	…	…	…	…	...	…
Protein, g MP/d	…	…	…	…	…	…	…	...	…
Energy allowable gain[h], kg/d	0.59	0.29	0.46	0.64	0.69	0.53	0.39	-0.04	0.64
Protein allowable gain[i], kg/d	0.39	0.19	0.31	0.51	0.62	0.54	0.43	0.00	0.78
Inputted gain[j], kg/d	0.39	0.19	0.31	0.51	0.62	0.53	0.39	-0.04	0.64
Feed energy balance[k], Mcal ME/d	0.9	0.5	0.8	0.8	0.5	0.0	0.0	-0.2	0.0
Required %	104.0	96.0	100.0	110.0	106.0	91.0	92.0	91.0	100.0
Feed protein balance[l], g MP/d	-51.0	-33.0	-41.0	-32.0	-21.0	-18.0	-10.0	1.0	44.0
Required %	82.0	86.0	85.0	90.0	95.0	96.0	98.0	100.0	108.0

Table 10 (continued)

Item	Postpuberty			Gestation (trimesters)					
	Grazing			1		2		3	
Forage season[a]	E	L	S	S	N	N	E	L	L
Heifer age	20-21	21-24	24-27	27-28	28-30	30-31	31-33	33-35	35-36
Forage DMI, kg/d	8.0	8.5	9.2	9.6	7.8	7.7	8.6	10.2	7.2
Forage ME intake, Mcal/d	17.1	17.1	18.0	18.9	14.0	14.0	18.6	20.5	14.7
Forage MP intake, g/d	623.0	648.0	651.0	683.0	464.0	460.0	674.0	781.0	548.0
Supplement, kg/d	…	…	…	…	…	...	…	…	1.5
Total DMI[b], kg/d	8.0	8.5	9.2	9.6	7.8	7.7	8.6	10.2	8.7
Total dietary energy[c], Mcal ME/d	17.1	17.1	18.0	18.9	14.0	14.0	18.6	20.5	19.4
Total dietary protein[d], g MP/d	623.0	648.0	651.0	683.0	464.0	460.0	674.0	781.0	716.0
Initial BW, kg	281	302	348	381	392	380	375	404	422
Mean BW, kg	292	325	365	387	386	378	390	413	424
Final BW, kg	302	348	381	392	380	375	404	422	426
Maintenance requirements[e]									
Energy, Mcal ME/d	10.4	11.4	13.5	14.2	14.8	14.3	12.4	10.4	11.8
Protein, g MP/d	363.0	397.0	455.0	476.0	432.0	423.0	390.0	472.0	376.0
Growth requirements[f]									
Energy, Mcal ME/d	6.7	5.7	4.5	4.6	0.0	0.0	5.3	3.8	1.5
Protein, g MP/d	203.0	153.0	115.0	115.0	0.0	0.0	148.0	99.0	52.0
Pregnancy requirements[g]									
Energy, Mcal ME/d	…	...	…	0.0	0.1	0.4	0.8	2.7	6.1
Protein, g MP/d	…	...	…	1.0	3.0	14.0	26.0	85.0	206.0
Energy allowable gain[h], kg/d	0.66	0.48	0.34	0.34	-0.20	-0.15	0.45	0.28	0.14
Protein allowable gain[i], kg/d	0.84	0.79	0.59	0.61	0.00	0.00	0.76	0.65	0.38
Inputted gain[j], kg/d	0.66	0.48	0.34	0.34	-0.20	-0.15	0.45	0.28	0.14
Feed energy balance[k], Mcal ME/d	0.0	0.0	0.0	0.0	-0.9	-0.7	0.0	0.0	0.0
Required %	100.0	96.0	97.0	100.0	94.0	95.0	100.0	100.0	100.0
Feed protein balance[l], g MP/d	58.0	80.0	68.0	92.0	28.0	24.0	111.0	125.0	83.0
Required %	110.0	114.0	112.0	115.0	106.0	106.0	120.0	119.0	113.0

[a] Length of grazing time that corresponds to the seasons of forage growth: early rains (E), late rains (L), scarce rain (S) and low rain (N).
[b] Total amount of dry matter intake from grazing forages and consuming commercial concentrates (when this applies).

Table 10 (continued)

[c] Energy supplied by the forage diet and commercial concentrates when they are used.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996).
[f] Amount of nutrients available from the diet after the maintenance requirements are covered.
[g] Nutrients required for gestation. The energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth.
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth.
[j] Average daily gain adjusted to the energy allowable gain.
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value indicates a decline in the average growth rate during a stage of growth; the value represents the amount of ME needed from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).

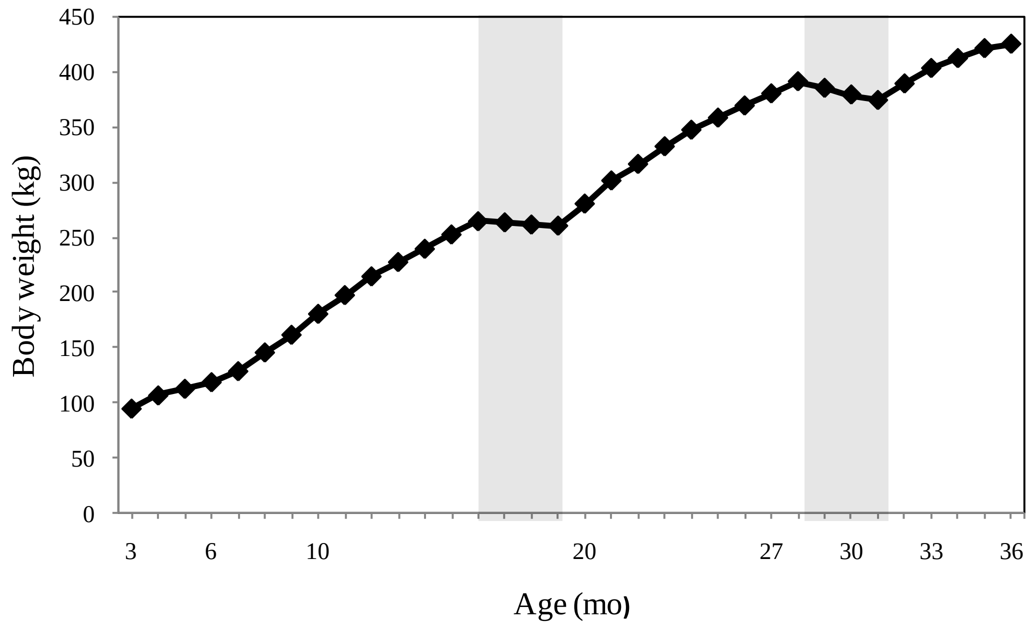


Figure 15. Predicted growth for heifers born at the onset of the scarce rain season (1 November). Shaded areas represent period of nutrient scarcity and consequent constraints on growth.

Figure 16 shows the average daily gains for animals born during the scarce rain season; these weight gains vary according to the season of grazing. The average growth rate during the prepuberty stage was 0.36 kg/d, whereas predicted growth during postpuberty and gestation averaged 0.47 and 0.16 kg/d, respectively. The rearing conditions and seasonal forage quality resulted in growth rates that varied from 0.66 kg/d for postpubertal heifers to BW losses of about -0.20 kg/d for pregnant heifers.

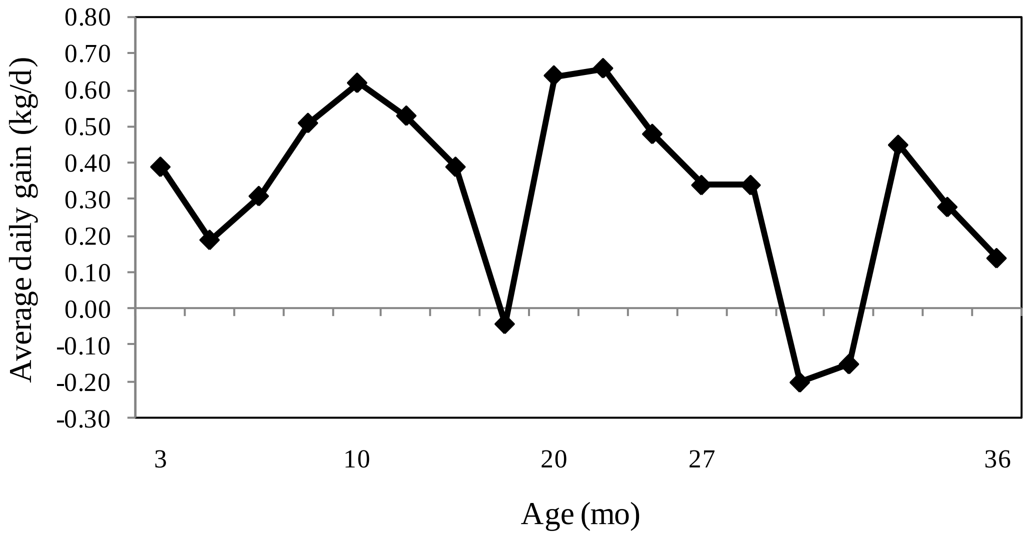


Figure 16. Predicted average daily gains for heifers born in the season of scarce rain (November 1).

Figure 17 shows seasonal variations in dietary nutrient balances identified in heifers receiving typical dietary management from weaning to calving. Dietary MP deficiencies were more limiting during early development until approximately 10 mo of age. MP balances ranged from -5% to -18% of the dietary requirement for growth, compared to the ME available in the diet. These deficiencies were attributed to the low protein content of the grass and the supplement. In older animals, dietary energy (ME) most limited growth, especially during the season of low rain with mobilizations of 0.2, 0.9 and 0.7 Mcal ME/d from body tissue reserves, which corresponded to prepuberty, and first and second trimesters of gestation. Figure 18 depicts ME utilization throughout physiological stages of development.

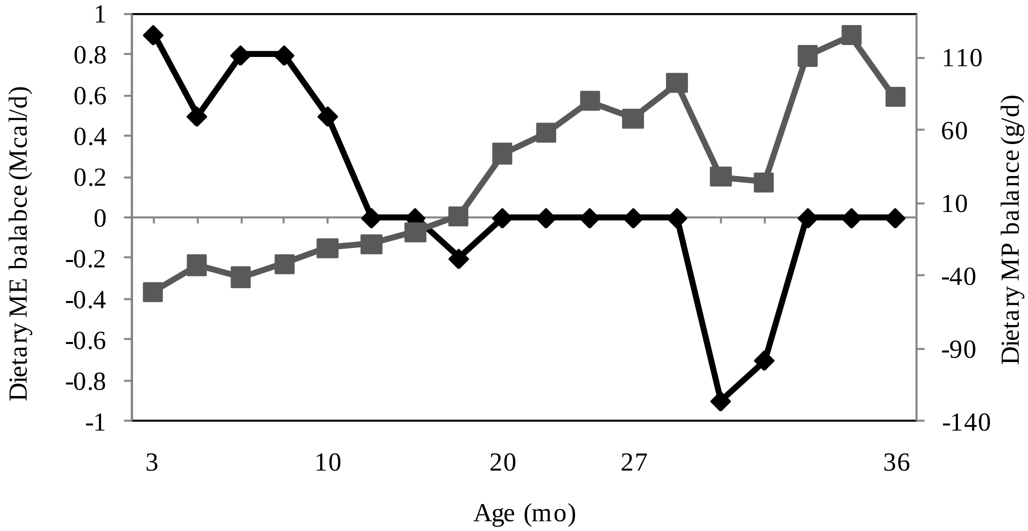


Figure 17. Predicted dietary balances of daily requirements for metabolizable energy (ME, ♦) and metabolizable protein (MP, ■) from weaning to first calving for heifers born in the season of scarce rains (1 November).

The highly variable ADG from weaning to calving averaged about 0.33 kg with an approximate predicted BW at calving of 426 kg with a BCS of ~2.75. First calving for animals in this management group is expected at the onset of the scarce rain season. Body weight at calving was similar to that for heifers in GGAVATT-Genesis herds at 38 mo of age (Absalon-Medina, 2008), which could be related to the season of birth (scarce rain for Tepetzintla and late rains for Genesis).

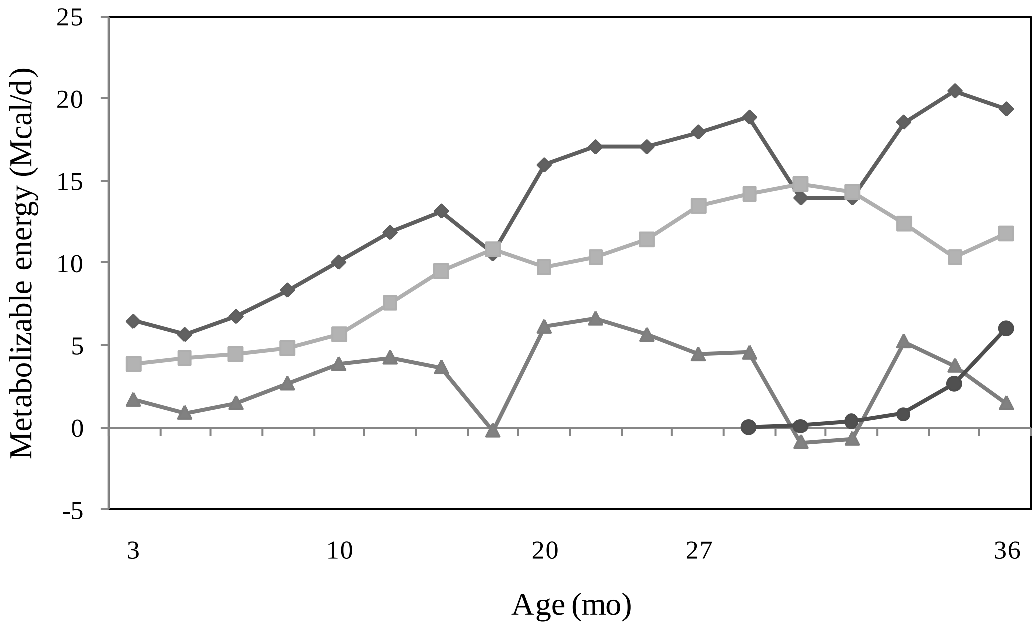


Figure 18. Feed energy intake (♦) partitioned among maintenance (■), growth (▲) and pregnancy (●) in different physiological stages of development in heifers born during the season of scarce rain (November 1).

5.2.4 Season of low rain

Heifers born in the season of low rain (March 1) are typically weaned in the season of early rains. The systematic evaluation for this group of heifers is shown in Table 11. Body weight changes in these animals are plotted in Figure 19. The expected body weights for puberty, conception and calving were 279, 389 and 436 kg, which were predicted to occur at 18, 30 and 39 mo of age, respectively. These outcomes closely agreed with those typically observed in GGAVATT-Tepetzintla (GGAVATT, personal communication). Significant losses in BW were repeatedly predicted during the ensuing dry seasons, when heifers are 12 to 15, 24 to 27 and 36 to 39 mo of age (Figure 15; shaded areas).

Table 11 Heifers reared in GGAVATT-Tepetzintla herds born in the season of low rain (March 1) under typical nutrition management: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty							
	Supplementation				Grazing			
Forage season[a]	E	L	L	S	S	N	E	L
Heifer age	3-5	5-6	6-8	8-10	10-12	12-15	15-17	17-18
Forage DMI, kg/d	2.3	3.1	3.2	3.8	6.2	5.3	6.2	7.4
Forage ME intake, Mcal/d	5.1	6.4	6.6	7.5	12.3	9.6	13.3	15.1
Forage MP intake, g/d	181.0	232.0	239.0	273.0	456.0	315.0	478.0	350.0
Supplement, kg/d	0.5	0.5	1.0	1.0	…	…	…	…
Total DMI[b], kg/d	2.8	3.6	4.2	4.8	6.2	5.3	6.2	7.4
Total dietary energy[c], Mcal ME/d	6.4	7.9	9.5	10.3	12.3	9.6	13.3	15.1
Total dietary protein[d], g MP/d	226.0	293.0	346.0	366.0	456.0	315.0	478.0	350.0
Initial BW, kg	95	121	137	176	205	230	230	263
Mean BW, kg	108	129	157	191	218	230	247	271
Final BW, kg	121	137	176	205	230	230	263	279
Maintenance requirements[e]								
Energy, Mcal ME/d	4.0	4.6	5.3	6.9	8.8	9.6	8.8	9.8
Protein, g MP/d	139.0	170.0	190.0	234.0	316.0	301.0	287.0	350.0
Growth requirements[f]								
Energy, Mcal ME/d	1.7	2.6	3.5	3.2	3.5	0.0	4.5	5.3
Protein, g MP/d	123.0	153.0	184.0	140.0	122.0	0.0	161.0	160.0
Pregnancy requirements[g]								
Energy, Mcal ME/d	…	…	…	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…	…	…	…
Energy allowable gain[h], kg/d	0.57	0.63	0.71	0.45	0.39	0.00	0.52	0.51
Protein allowable gain[i], kg/d	0.40	0.50	0.60	0.48	0.45	0.00	0.61	0.69
Inputted gain[j], kg/d	0.40	0.50	0.60	0.45	0.39	0.00	0.52	0.51
Feed energy balance[k], Mcal ME/d	0.8	0.7	0.7	0.2	0.0	0.0	0.0	0.0
Required %	101.0	98.0	98.0	92.0	91.0	89.0	93.0	94.0
Feed protein balance[l], g MP/d	-49.0	-46.0	-45.0	-29.0	-7.0	-8.0	11.0	39.0
Required %	82.0	86.0	89.0	93.0	98.0	97.0	102.0	107.0

Table 11 (continued)

Item	Postpuberty					Gestation				
	Grazing					1/3		2/3	3/3	
Forage season[a]	L	S	N	E	L	L	S	S	N	N
Heifer age	17-20	20-24	24-27	27-29	29-30	30-32	32-33	33-36	36-38	38-39
Forage DMI, kg/d	7.9	8.5	7.3	8.2	9.6	10.0	10.3	10.5	8.9	6.7
Forage ME intake, Mcal/d	16.0	16.8	13.1	17.5	19.4	20.5	20.8	21.5	17.1	13.5
Forage MP intake, g/d	603.0	628.0	432.0	635.0	735.0	773.0	775.0	796.0	487.0	429.0
Supplement, kg/d	…	…	…	…		…	…	…	…	1.5
Total DMI[b], kg/d	7.9	8.5	7.3	8.2	9.6	10.0	10.3	10.5	8.9	8.2
Total dietary energy[c], Mcal ME/d	16.0	16.8	13.1	17.5	19.4	20.5	20.8	21.5	17.1	18.2
Total dietary protein[d], g MP/d	603.0	628.0	432.0	635.0	735.0	773.0	775.0	796.0	487.0	598.0
Initial BW, kg	279	311	355	343	374	389	420	431	465	437
Mean BW, kg	295	333	349	359	382	405	426	448	451	437
Final BW, kg	311	355	343	374	389	420	431	465	437	436
Maintenance requirements[e]										
Energy, Mcal ME/d	10.5	12.5	13.7	12.0	13.1	13.7	15.4	15.6	17.1	12.3
Protein, g MP/d	371.0	426.0	405.0	374.0	447.0	465.0	510.0	519.0	487.0	405.0
Growth requirements[f]										
Energy, Mcal ME/d	5.5	4.2	0.0	5.5	6.2	6.8	5.2	5.3	0.0	0.0
Protein, g MP/d	158.0	113.0	0.0	156.0	153.0	163.0	122.0	124.0	0.0	0.0
Pregnancy requirements[g]										
Energy, Mcal ME/d	…	…	…	…	…	0.0	0.1	0.6	2.7	6.1
Protein, g MP/d	…	…	…	…	…	2.0	5.0	19.0	85.0	206.0
Energy allowable gain[h], kg/d	0.50	0.35	-0.13	0.48	0.46	0.49	0.35	0.35	-0.46	-0.04
Protein allowable gain[i], kg/d	0.73	0.62	0.00	0.80	0.86	0.87	0.67	0.61	0.00	0.00
Inputted gain[j], kg/d	0.50	0.35	-0.13	0.48	0.46	0.49	0.35	0.35	-0.46	-0.04
Feed energy balance[k], Mcal ME/d	0.0	0.0	-0.6	0.0	0.0	0.0	0.0	0.0	-2.1	-0.2
Required %	100.0	95.0	90.0	97.0	100.0	100.0	100.0	100.0	90.0	99.0
Feed protein balance[l], g MP/d	74.0	68.0	7.0	93.0	135.0	144.0	138.0	137.0	0.0	-12.0
Required %	114.0	112.0	102.0	117.0	122.0	123.0	122.0	121.0	100.0	98.0

[a] Length of grazing time that corresponds to the seasons of forage growth: early rains (E), late rains (L), scarce rain (S) and low rain (N).

[b] Total amount of dry matter intake from grazing forages and consuming commercial concentrates (when this applies).

Table 11 (continued)

[c] Energy supplied by the forage diet and commercial concentrates when the latter are supplemented.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996).
[f] Amount of nutrients available from the diet after the maintenance requirements are covered.
[g] Nutrients required for gestation. The energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth.
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth.
[j] Average daily gain adjusted to the energy allowable gain.
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value indicates a decline in the average growth rate during a stage of growth; the value represents the amount of ME needed from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).

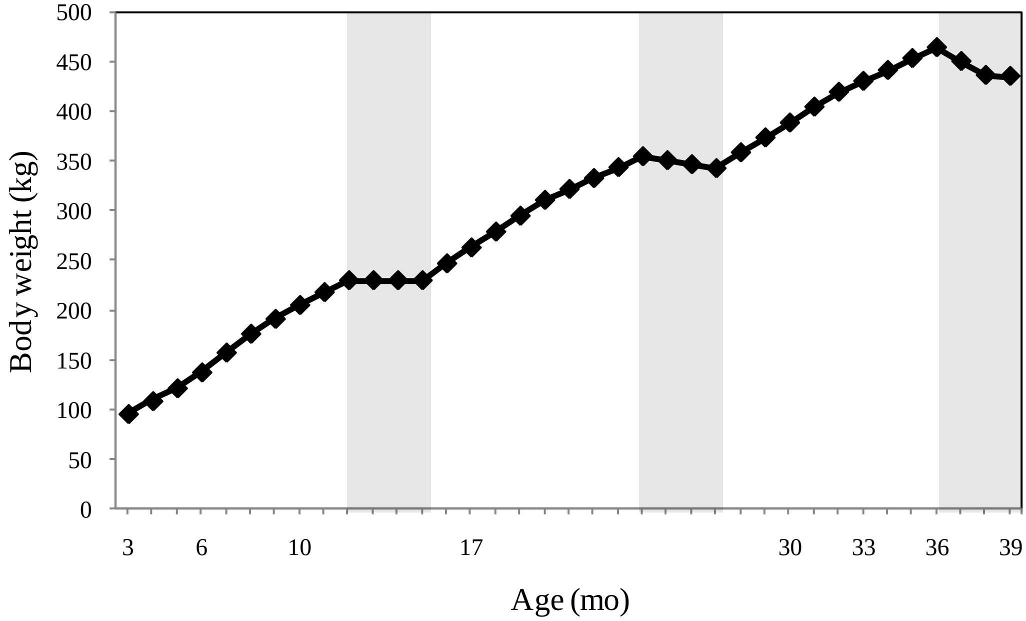


Figure 19. Predicted growth for heifers born at the onset of the low rain season (1 March). Shaded areas represent periods of nutrient scarcity and consequent constraints on growth.

Average daily gains of animals born during the low rain season are shown in Figure 20. The average weight gains by physiological stage of development were 0.40, 0.30 and 0.17 kg/d during prepuberty, postpuberty and late gestation, respectively. Daily weight gains varied widely from 0.60 kg for prepubertal heifers with rotational grazing and supplementation to BW losses of 0.46 kg for heifers in the final trimester of gestation grazing without supplementation.

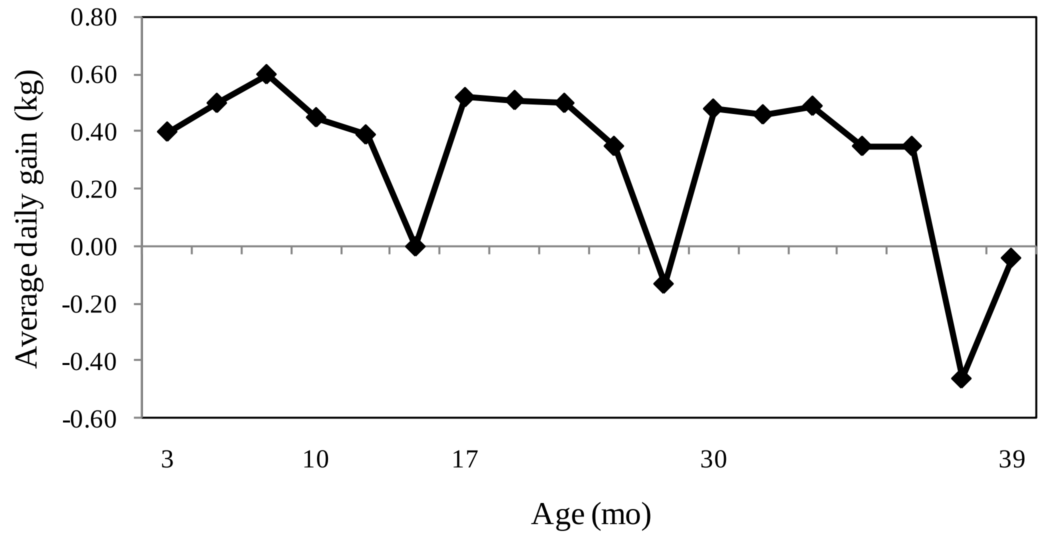


Figure 20. Predicted average daily gains for heifers born in the low rain season (March 1).

Figure 21 shows dietary nutrient balances from weaning to calving for heifers born in the season of low rain. During the initial months of development until approximately 10 mo of age, dietary MP was most limiting. Negative MP balances ranged from -7% to -18% of the requirement. From 10 mo until calving ME was the primary constraint on growth. ME deficiencies were most severe during the low rain season, especially in the seventh and eighth months of pregnancy when approximately 2.1 Mcal ME/d were mobilized from body tissues. Figure 22 shows ME utilization throughout physiological stages of development.

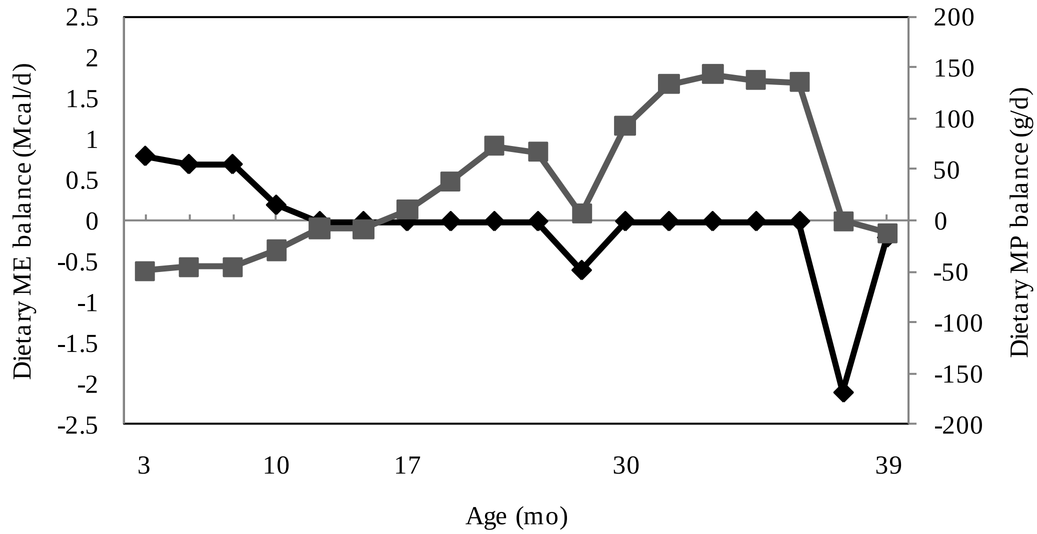


Figure 21. Predicted dietary balances as a percentage of daily requirements for metabolizable energy (ME, ♦) and metabolizable protein (MP, ■) from weaning to first calving for heifers born in the season of low rain (March 1).

The ADG for this group of heifers from weaning to calving was about 0.31 kg. The predicted age at calving was about 39 mo with a BW of 436 kg and BCS ~3.0. The BW at calving exceeded the 410 kg (38 mo of age) assumed typical in GGAVATT-Genesis herds for heifers calving during the low rain season (Absalon-Medina, 2008). Dietary management during the last month of gestation might explain such differences in BW for heifers calving during the low rain season. Typically, heifers reared in GGAVATT-Tepetzintla receive 1.5 kg/d of supplementation during the last month of pregnancy, which avoids the mobilization of BW tissues to sustain the increased fetal requirements, while Genesis heifers do not receive supplementation and probably mobilize tissue reserves because of insufficient energy intake from grazing.

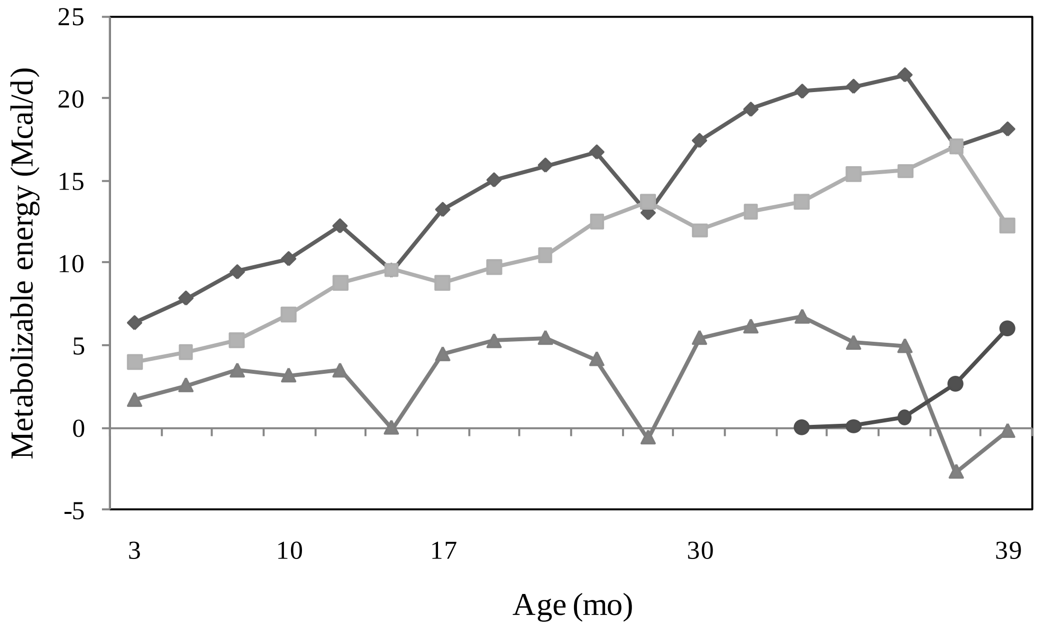


Figure 22. Feed energy intake (♦) partitioned among maintenance (■), growth (▲) and pregnancy (●) in different physiological stages of development in heifers born during the low rain season (March 1).

Figure 23 consolidates the growth curves for heifers in the four management groups by season of birth. Consistent patterns of growth were predicted with high growth rates expected in the rainy seasons and subsequent declines in the dry ones. Moreover, tissue accretion was arrested in all groups during the dry season of forage nutrient scarcity, forcing the catabolism of body tissues. The interaction of growth with grazing seasons, led to age differences in reaching puberty, conception and, consequently, age at first calving (Figure 23). For example, heifers born during the seasons of late and low rains were 17 mo of age at puberty, while the older heifers at puberty corresponded to the animals that were born during the scarce rain season, averaging 20 mo of age. For the age at calving, the heifers born in the season of scarce rains were the youngest, averaging about 36 mo, which was three months earlier than for heifers born in the season of low rain. These interactions reflect the seasonal pattern of growth that DP heifers experience under traditional management.

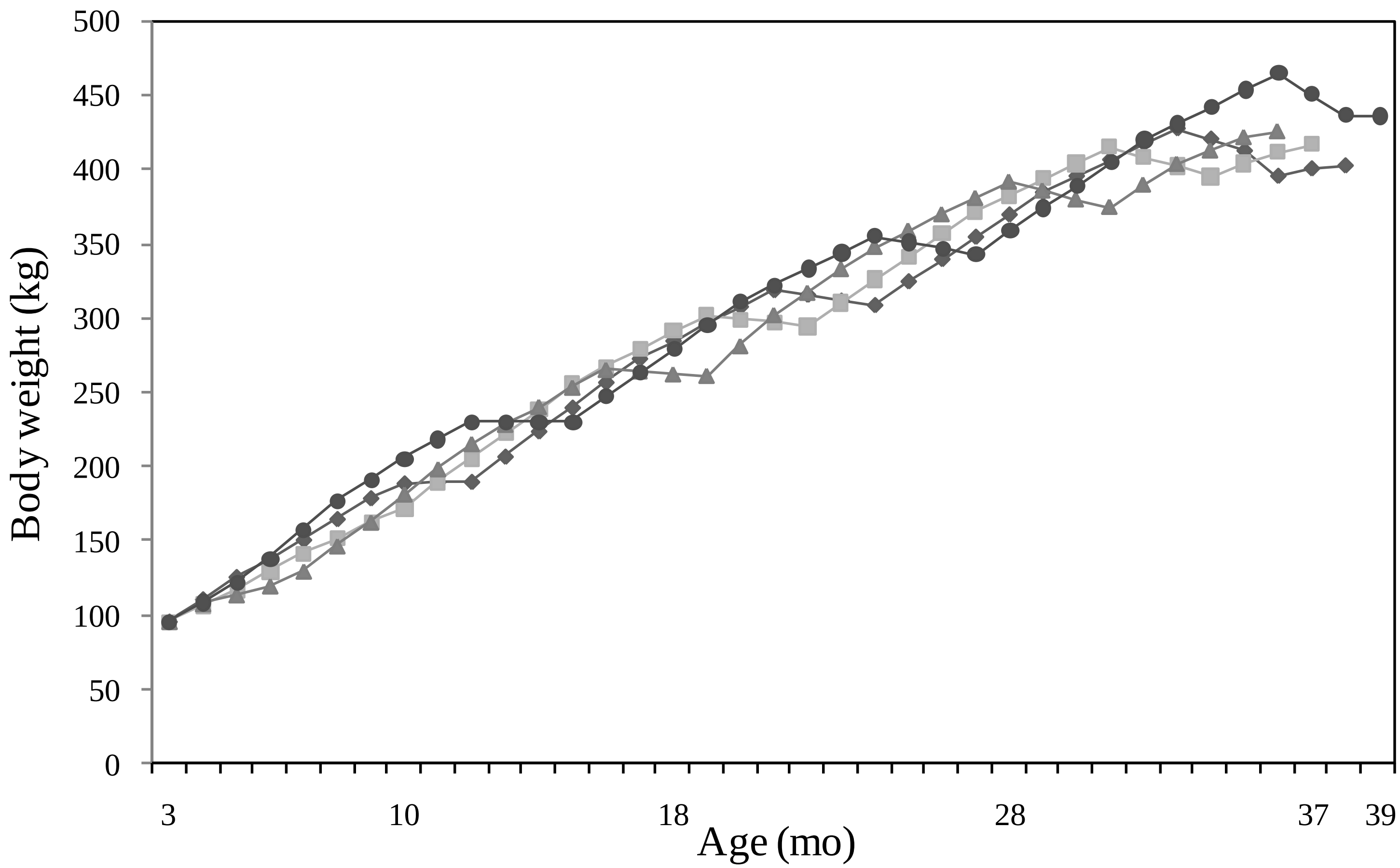


Figure 23. Summary of the growth curves for each management group. Heifers born in the season of early rains (♦), calving at 38 mo and weighing 402 kg; heifers born in the season of late rains (■), calving at 37 mo and weighing 417 kg; heifers born in the season of scarce rain (▲), calving at 36 mo and weighing 426 kg; and heifers born in the season of low rain (●), calving at 39 mo and weighing 436 kg.

5.3 Summary and discussion of the baseline simulations by physiological stage of development

Systematic evaluation of the growth of heifers born at the onset of each grazing season of the year revealed consistent repeated restrictions on predicted average daily gains in various physiological stages of development. Variations in growth performance were influenced by management and grazing season. Growth during the prepubertal stage averaged 0.40 kg/d, which was supported by supplementation and grazing management during the first 7 mo after weaning (0.43 kg/d), declining slightly from 10 mo until puberty (0.38 kg/d) when heifers were reared only by grazing. After puberty, growth was about 0.35 kg/d from the continuous grazing of seasonal forage supplies. The smallest daily gains occurred during gestation, when heifer growth averaged about 0.13 kg/d. Pregnant animals grazed continuously without supplementation except for the final month of gestation (rotational grazing with supplementation).

Based on CNCPS-predictions, the preponderance of MP deficits occurring during the early prepubertal stage of development was consistent for all seasons of birth. Negative MP dietary balances constrained growth during the seven-month period after weaning with MP deficiencies ranging from 8 to 17% of daily requirements as animals approach 10 mo of age. This period coincided with supplementation, during which the commercial concentrate (formulated for milking cows) contributed large amounts of ME (3.0 Mcal ME/kg) but little MP (68 g/kg), which, combined with the low protein content of the available forage (Juárez-Lagunes et al., 2002a), resulted in curtailed growth. Van Amburgh and Fox (1996) indicated that protein deposition and the efficiency with which this is used for growth is higher during earlier stages of development (i.e., prepuberty), which decreases with advancing age. It has also been assumed that when energy intake surpasses maintenance requirements, the rate of protein synthesis becomes first limiting, and then extra energy is deposited as fat (Fox et al., 1999).

The tendency of less protein being required for weight gain has been indicated as BW increases (Fox et al., 1999; NRC, 2001; Van Amburgh, 2004). After ten months of age, heifers in GGAVATT-Tepetzintla are reared on paddocks with seasonal grazing. This practice promotes a seasonal pattern of growth responses as a consequence of the quality and intake of forages. Variations in forage quality have been observed to affect animal performance (Juárez-Lagunes et al., 2002a; Juárez et al., 1999; Licitra et al., 1998; Rueda et al., 2003). Good quality forages during the rainy season have been associated with increased animal production, whereas mature pastures constrain the expression of genetic potential (Absalon-Medina, 2008; Baba, 2007; Licitra et al., 1998). In this study, reduced growth was consistent for all management groups in the dry season (seasons of scarce and low rain). Moreover, dietary nutrient intake during the low rain season was constrained by a decline in forage supply (10% restriction on *ad libitum* intake) and forage quality, which resulted in dietary energy intake insufficient to meet maintenance requirements, and with consequent catabolism of body tissues. Several studies have pointed out that short-term dietary nutrient restrictions in early development may be counterbalanced by subsequent compensatory growth, especially when animals are re-fed with diets rich in nutrients (Carstens et al., 1991; Ellenberger et al., 1989; Hayden et al., 1993; Rompala et al., 1985). Unfortunately, the concentration of nutrients in tropical forages may not be enough for catch up to be expressed. However, the compensatory growth phenomenon could be exploited in management to help animals recover from periods of slowed growth, as proposed by Urbina (1991).

Dietary protein and energy deficiencies during the prepubertal and postpubertal periods, respectively, might result in lengthened periods from weaning to breeding, which may signify more rearing days until first calving and thus lower production during a cow's lifetime. Several studies reported that the reproductive management of DP heifers does not begin with puberty. In fact, breeding is typically delayed when growth rates are <0.35 kg/d (González-Stagnaro, 1995). In Latin America, DP heifers are frequently bred when they achieve about 70 to 75% of their mature body weight (González-Stagnaro, 1995). Similar proportions of mature body weight for mating in GGAVATT-Tepetzintla heifers were expected in this study due to the low growth rates predicted. In addition, systematic evaluations of beef and DP cattle in Mexico indicated that undesirable energy deficiencies during the dry period (pregnancy) may constrain the productive lifetime (Baba, 2007; Absalon-Medina, 2008). Dietary energy deficiencies during pregnancy result in smaller cows with less feed intake capacity, reduced milk production and prolonged calving intervals (Deresz et al., 1987; Urbina, 1991; Avila, 1995; Baba, 2007; Absalon-Medina, 2008).

5.4 Conclusions about key dietary management constraints on replacement heifers

Table 12 shows CNCPS-predicted growth performance for heifers born in different seasons of the year. Results from simulations closely agree with the overall GGAVATT-Tepetzintla herd reports (GGAVATT-Tepetzintla, personal communication). Inputs required for the CNCPS model involved animal characteristics, description and chemical composition of the diet, and environmental and management conditions. The systematic use of this information through specified scenarios evaluated with the CNCPS model proved effective in describing typical ages and growth rates by physiological stage of development in this herd population. Since CNCPS-predicted outcomes generally agree with the GGAVATT farmers' observations, nutritional constraints on production can be identified and feeding schemes can be developed to reduce constraints through acceptable management options for the DP cattle enterprises.

Table 12. Simple and weighted average body weight (BW, kg) and age (mo) for heifers in different physiological stages of development and born in different forage seasons of the year.

Birth season[a]	Puberty		Conception		Calving	
	BW	Age	BW	Age	BW	Age
Early rains	284	18	384	29	402	38
Late rains	279	17	383	28	417	37
Scarce rain	281	20	381	27	426	36
Low rain	279	17	389	30	436	39
CNCPS-predicted average[b]	281	18	384	29	420	38
GGAVATT-observed average[c]	280	17	380	28	450	37

[a] Approximate birth frequencies by season of the year are: early rains (14%), late rains (26%), scarce rain (32%) and low rain (28%).
[b] Average values from the four birth seasons predicted by the CNCPS at each phase of development.
[c] Average values observed by the GGAVATT farmers at each phase of development.

Based on predicted performance during the seven-month period after weaning, protein deficiencies most limited BW gains in early life. During this time, calves are regularly supplemented with commercial concentrates formulated for milking cows (3.0 Mcal ME/kg and 68 g MP/kg). This supplementation, coupled with seasonal forages, resulted in diets relatively rich in energy but low in protein for juvenile animals. Therefore, GGAVATT farmers would likely benefit from investments in better meeting MP requirements during the prepubertal period of growth. The inclusion of protein sources, like legumes, in the diets of young animals could promote more rapid growth rates by improving forage digestibility and providing by-pass protein (Osborn, 2000; Shelton, 2004, Ramírez-Restrepo and Barry, 2005). Moreover, during this rearing time a valuable option for reducing supplementation costs could be the utilization of hay made from good quality forages with higher energy and protein contents than typically utilized by GGAVATT-Tepetzintla owners.

The systematic nutritional evaluation of heifers born at the onset of the four defined seasons of the year revealed a pattern of important bottlenecks in growth performance. Generally, animals older than 10 mo of age tended to be energetically restricted. The inclusion of energy feedstuffs in the diets of these heifers could avoid BW losses and produce modest growth rates, instead of tissue losses, during critical seasons. The utilization of improved forages and sugar cane could supply needed energy in support of modest growth during the dry season. Sugarcane is available on GGAVATT-Tepetzintla farms. This feedstuff could be used to improve dietary energy intakes to avoid BW losses and sustain modest growth rates. The use of hay made from improved forages (e.g., cv. Mulato, Llanero) could result in enhanced growth performance by increasing dietary nutrient supply, which may reduce the need for commercial supplementation. In addition, the use of forage legumes during critical seasons might alleviate protein deficiencies, resulting in greater voluntary dry matter intake and improved overall digestibility of the diet. Therefore, the use of legumes could result in less energy supplementation to achieve desired age, body condition and body weights at calving. Supplementation with sorghum grain or local by-products (citrus pulp), which are less expensive than commercial concentrates, may help provide needed critical supplies of energy to meet requirements during the final month of pregnancy. Although these feedstuffs can be used, they may be prohibitively expensive. For this reason economic assessment is a needed part of the technology assessment. It may be advisable to restrict the use of supplementation using cereal grain to heifers in late pregnancy or other key time periods during development.

In summary, the proper use of feed resources available in the tropics, such as those found in GGAVATT-Tepetzintla, could assuage dietary nutrient constraints and improve future animal performance. Feeding management programs by physiological stage of development or during seasons with dietary constraints may be beneficial. For example, the inclusion of legumes in diets for post-weaned heifers may alleviate protein deficiencies and reduce the cost of commercial supplementation. Animals older than 10 mo might be supplemented with cheap sources of energy and protein such as farm-produced sugar cane and legumes, which may compensate for the otherwise low dry matter intake and low energy content of grasses during critical seasons of the year (dry seasons). Finally, heifers in the last month of gestation may be supplemented with sorghum grain to provide the needed energy, which would avoid the mobilization of maternal tissues to supply the increased nutrient demands of the fetus. These are some of the nutrition management interventions to be evaluated in the next chapter with a goal of reducing average age at first calving.

6.0 **Results and discussion:** Management options for GGAVATT-Tepetzintla herd owners to improve dietary support of replacement heifers

This chapter evaluates selected alternative diets to alleviate the identified bottlenecks (Chapter 5) in heifer growth under typical GGAVATT-Tepetzintla conditions. Alternative diets consist of improved and harvested forages already used by GGAVATT farmers, and commercial feedstuffs that are readily found in the region. Section 6.2 summarizes predicted animal performance by nutritional intervention of alternative diets for heifers born at the onset of each grazing season of the year. Section 6.3 suggests possible interventions to improve the management and to save on rearing costs of pre-weaned calves. Finally, section 6.4 compares the costs of feeding typical diets versus improved diets in the rearing period from weaning to calving for GGAVATT-Tepetzintla replacement females.

6.1 Alternative dietary management and heifer productivity outcomes

The following section contains results from alternative dietary management used to alleviate the identified bottlenecks from Chapter 5 for heifers born in each season of the year. Figures summarize expected BW, growth rates and feed nutrient status of heifers throughout physiological stages of growth (and coinciding seasons of the year).

6.1.1 Season of early rains

Systematic evaluation of heifers born in the season of early rain (June 1) receiving alternative dietary management is shown in Appendix Table 11.1. Body weight accretion is summarized in Figure 24. Predicted average BW at puberty, conception and calving were 279, 351 and 444 kg, and were expected to occur at 15, 21 and 30 mo of age. Compared with their counterparts receiving traditional management, these heifers were expected to reach pubertal BW 3 mo earlier, to conceive 8 mo younger, and to calve 7 mo younger at 30 mo of age weighing 444 kg. The graph shows how the BW losses were alleviated during the pre- and postpubertal rearing periods, which reduced the number of days and increased ADG from weaning to calving compared to the typical pattern of bottlenecks (shaded areas) shown in Figure 7.

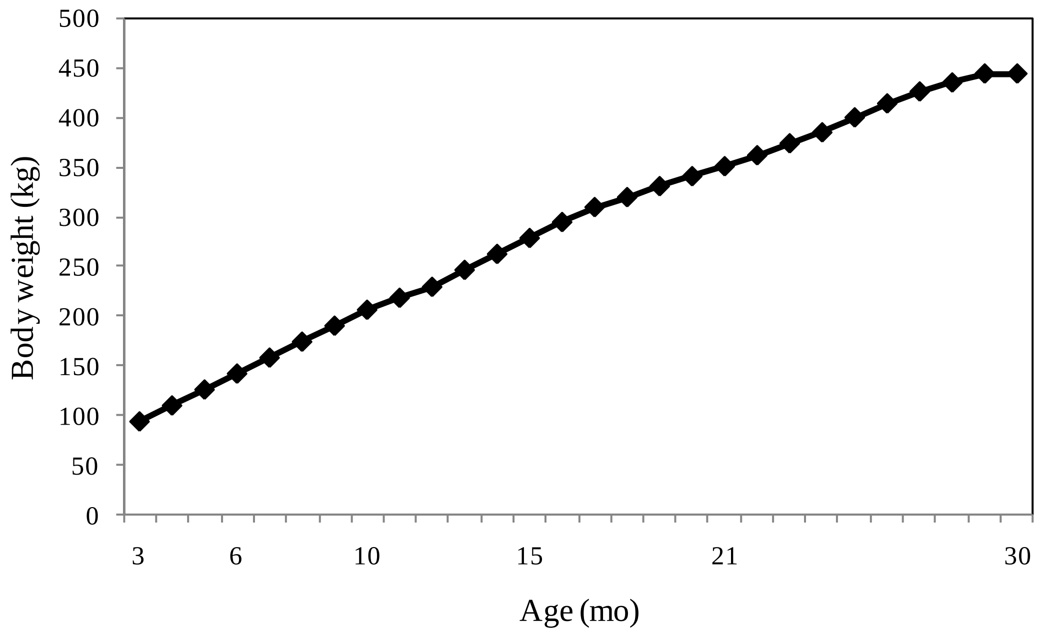


Figure 24. Predicted growth for heifers born at the onset of the season of early rains (June 1) receiving improved dietary management.

Figure 25 shows the expected growth rates using alternative dietary management. Expected daily gains during prepuberty, postpuberty and gestation were 0.50, 0.39 and 0.34 kg/d, respectively. Average daily gains for improved dietary management resulted in growth increases in each physiological stage of development of 22%, 31% and 385% compared to expectations under traditional management.

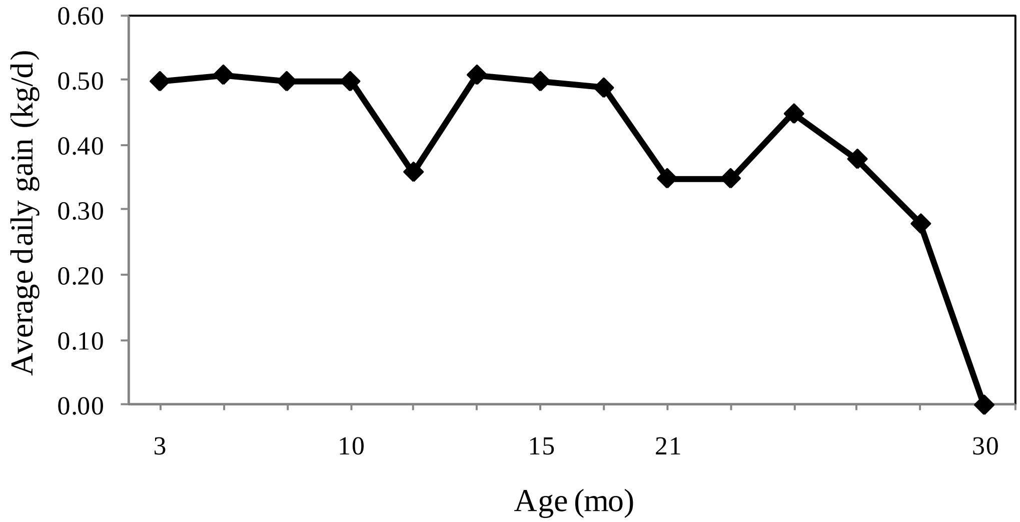


Figure 25. Predicted average daily gains for heifers born in the season of early rains (June 1) receiving improved dietary management.

6.1.2 Season of late rains

The systematic evaluation of growth for heifers fed with alternative diets and born in the season of late rains (August 1) is detailed in the Appendix Table 11.2. Growth from weaning to calving is portrayed in Figure 26. Predicted BW at puberty, conception and calving were 287, 354 and 449 kg, which were expected to occur at 15, 21 and 30 mo of age. This management group of heifers was expected to achieve puberty two months earlier, to be mated 7 mo younger, and to also calve at 30 mo with 8% greater BW than their counterparts receiving typical management. The alleviation of BW losses during pre- and postpubertal rearing periods resulted in faster growth rates and shorter intervals from weaning to calving compared to traditional management (Figure 11).

Figure 26. Predicted growth for heifers born at the onset of the season of late rains (August 1) receiving improved dietary management.

Figure 27 represents the average daily gains for heifers born in the season of late rains, which received alternative dietary management. Growth rates by physiological stage were 0.52, 0.37 and 0.35 kg/d during the prepuberty, postpuberty and gestation, respectively. The BW gains during these physiological stages were 22, 18 and 189% higher, respectively, than under traditional management.

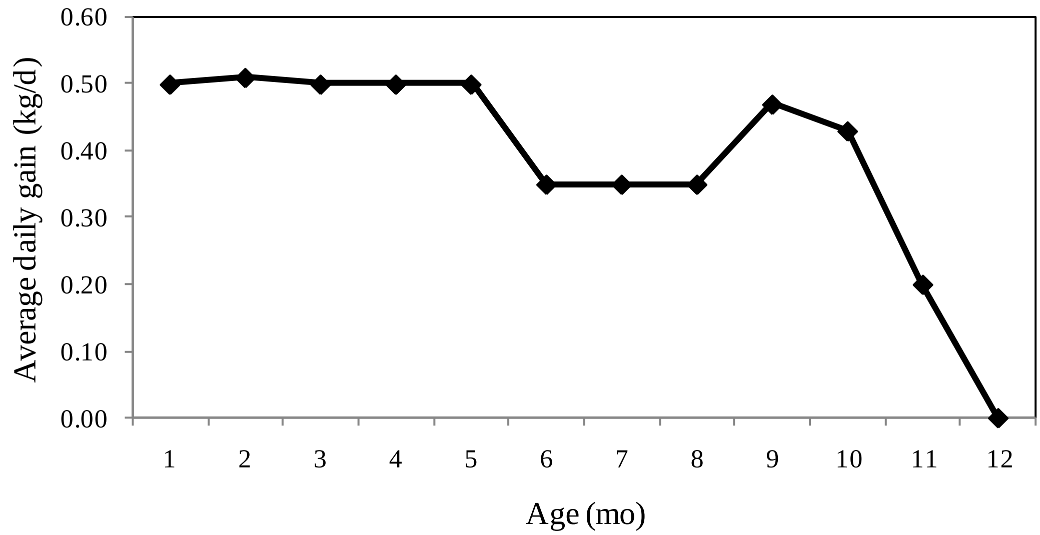


Figure 27. Predicted average daily gains for heifers born in the season of late rains (August 1) receiving improved dietary management.

6.1.3 Season of scarce rain

Expected responses for heifers born at the onset of the scarce rain season (1 November) and supplemented with better quality diets are detailed in Appendix Table 11.3. Changes from weaning to calving are graphed in Figure 28. Predicted BW at puberty, conception and calving were 280, 358 and 445 kg, which were predicted to occur at 15, 21 and 30 mo. Improved dietary management resulted in heifers that were 5 mo younger at puberty, 6 mo younger at breeding, and also calved 5% heavier at 30 mo of age. This figure for alternative management also illustrates a quasi-linear growth response without the BW losses that typically occur with traditional management (Figure 15).

Figure 28. Predicted growth for heifers born at the onset of the scarce rain season (November 1) receiving improved dietary management.

Figure 29 shows the ADG for animals born during the scare rain season and supplemented with alternative dietary management. Average growth rates during prepuberty, postpuberty and gestation were 0.51, 0.43 and 0.32 kg/d, respectively. Prepubertal and pregnant heifers with improved dietary management had 41% and 98% better growth performance, respectively, compared to traditionally managed animals. Postpubertal heifers under traditional management, however, had 9% greater rates of gain because they coincided with the rainy season while heifers receiving alternative management encountered the dry season during this stage of their development.

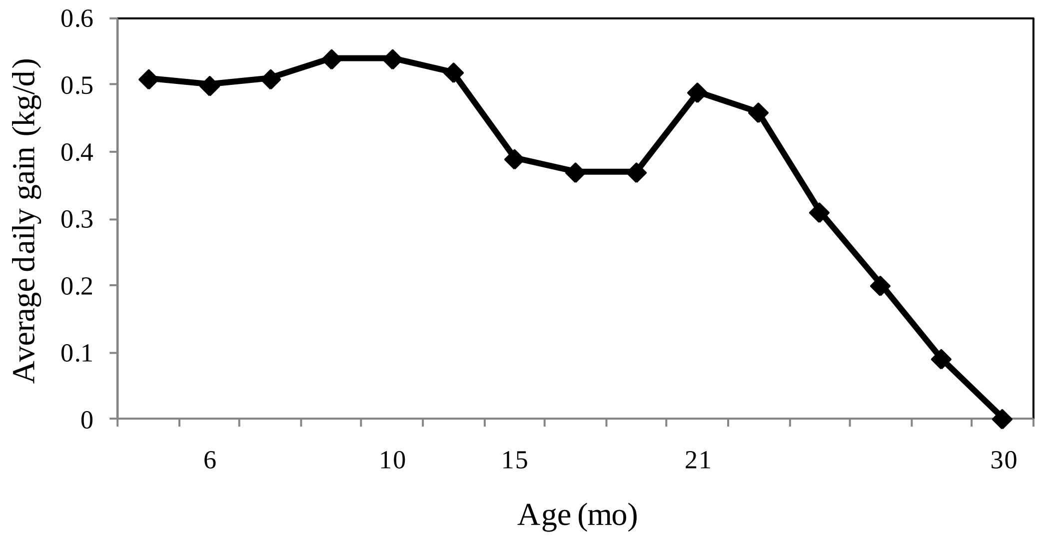


Figure 29. Predicted average daily gains for heifers born in the season of scarce rains (November 1) receiving improved dietary management.

6.1.4 Season of low rain

The systematic evaluation for this group of heifers receiving alternative dietary management is shown in Appendix Table 11.4. The expected body weight changes in these heifers are summarized in Figure 30. Expected body weights at puberty, conception and calving were 282, 356 and 440 kg, which were predicted to occur at 16, 21 and 30 mo of age, respectively. Heifers receiving improved dietary management were 2 mo younger at puberty and 9 mo younger at calving than those traditionally managed; body weight at calving was about the same.

Figure 30. Predicted growth for heifers born at the onset of the low rain season (March 1) receiving improved dietary management.

Figure 31 shows daily weight gain responses for animals born during the low rain season, which are supported by improved dietary alternatives. The average weight gains by physiological stage of development were 0.51, 0.43 and 0.30 kg/d during prepuberty, postpuberty and gestation. The alleviation of nutritional constants resulted in BW increases of about 27%, 42% and 76% during each stage of development compared to typical management.

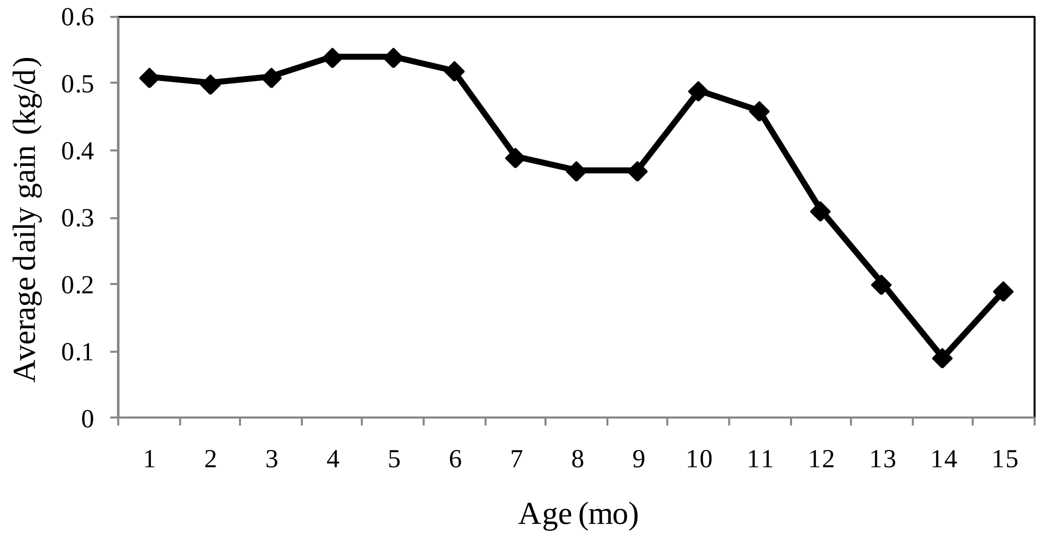


Figure 31. Predicted average daily gains for heifers born in the season of low rain (March 1) receiving improved dietary management.

Figure 32 compares heifers born in the scarce and low rain seasons managed under typical GGAVATT diets (the best and worst scenarios, respectively) with their counterparts receiving alternative dietary management. Growth bottlenecks observed with traditional dietary management (reported in Chapter 5) resulted in different ages and weights by physiological stage of development. However, alternative diets, especially during critical periods of arrested growth and development, smoothed the curves of the overall growth performance and expected age at parturition. For example, the age at puberty for heifers born in the scarce rain season, in the traditional management was 20 mo and for heifers born in the low rain season was about 17 mo, when their counterparts averaged 15 mo. Growth inconsistencies for the indicated groups reared traditionally can be observed at calving. Heifers born in the scarce rain season typically calve at about 36 mo, while the group born in the low rain season, which reached puberty sooner, calved about 39 mo. The improved dietary management resulted in the same average age at calving of 30 mo for both heifer groups. Body weights at calving under traditional management were heavier for heifers calving at 39 mo (436 kg) than for those calving at 36 mo (426 kg). However, heifers fed with good quality diets achieved yet heavier weights (~440 kg) although they were 6 and 9 mo younger than typically managed heifers in GGAVATT herds.

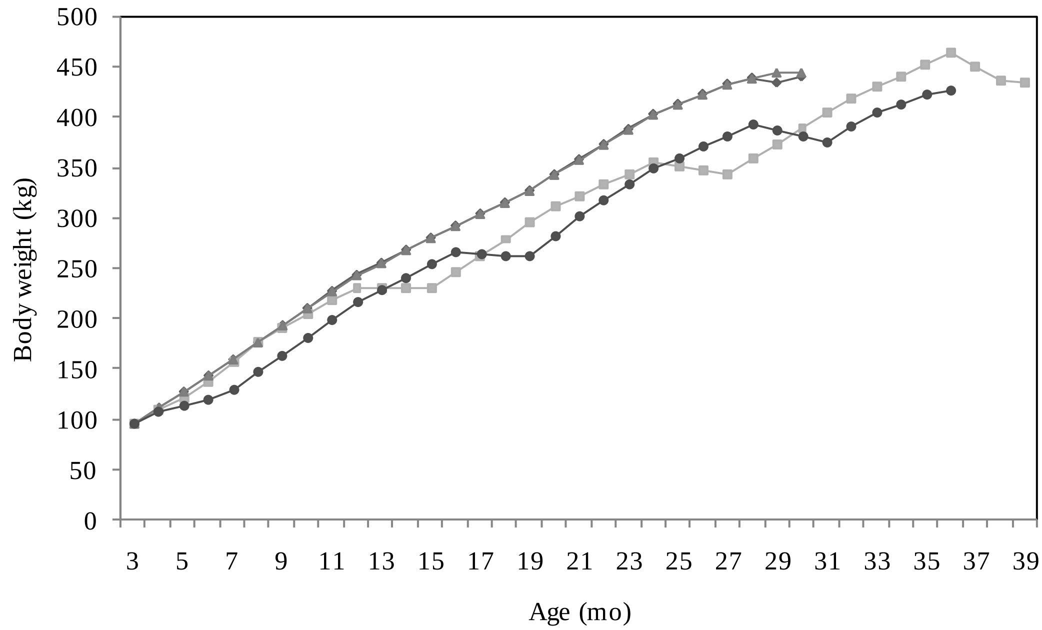


Figure 32. Comparisons between the best and worst case scenarios under typical management and alternative dietary management. Heifers born in the season of scarce rain receiving typical management (●); heifers born in the season of low rain receiving typical management (■); heifers born in the season of scarce rain with alternative dietary management (▲); and heifers born in the season of low rain with alternative dietary management (♦).

6.2 Summary of expected performance from alternative diets to alleviate typical bottlenecks in animal growth

This section summarizes the predicted animal performance by intervening to alleviate nutritional constraints using alternative diets for heifers born at the onset of each forage season of the year. Relevant interventions were based on key constraints identified in chapter 5. Alternative diets consisted of legumes (*Leucaena* *leucocephala*), hay of improved forages (*Brachiaria* hybrids cv. mulato), sugar cane and sorghum grain (Table 4). Tables in Appendix 11 contain detailed information about nutritional status and heifer growth performance.

6.2.1 Increasing the metabolizable protein for growth in the diets of young heifers

The first intervention consisted of increasing the dietary intake of MP in prepubertal heifers (from 3 to 10 mo) and, consequently, the ADG with a growth target of about 0.50 kg/d. To attain this goal, forage from legume (*Leucaena leucocephala*) sources was chosen to reduce dietary deficits in MP. Hay of good quality forages was also used to improve the dietary nutrient intake from typical grazed forages and to restrict the utilization of commercial supplements (sorghum grain). However, although grains are expensive, they were not completely substituted. Several studies have demonstrated that propionate and butyrate, which are produced by cereal fermentation, promote rumen development by stimulating rumen papillae growth (Van Soest, 1994). Therefore, the alternative diet of post-weaned calves included about 10% of sorghum grain on a DM basis.

Table 13 shows the predicted DMI for grasses, sorghum, legumes and hay provided to each heifer group during the seven-month growing period to achieve growth of about 0.50 kg/d. Adjustments in the amounts of supplementation for each heifer group can be explained by seasonal grass quality in which each group was weaned and grazed. For example, heifers born in the season of late rains are generally weaned during the dry season, which signifies increased need to supplement the poor quality and low availability of grasses (Appendix Table 11.2), whereas heifers born during the low rain season are weaned at the onset of the rainy season, which supplies plentiful forages of good quality and a reduced need for dietary supplementation (Appendix Table 11.4).

Table 13. Summary of the diet composition required for prepubertal heifers born in alternative seasons of the year to obtain target body weight gains of about 0.50 kg/d during the seven months after weaning.

Birth season	Sorghum, total DMI, kg	Legume, total DMI, kg	Hay, total DMI, kg
Early rains	97	85	201
Late rains	101	95	211
Scarce rain	91	91	170
Low rain	76	82	170

A growth rate of 0.50 kg/d until 10 mo of age resulted in heifers weighing about 209 kg, which was 20 kg more than that predicted for heifers receiving traditional management. Galves-Olvera et al. (1987) reported weights of 210 kg for Brown Swiss calves grazed on African star grass and supplemented daily with 1 or 2 kg commercial concentrate from weaning (3 mo) until 10 mo of age at the INIFAP research station “Las Margaritas”, Puebla, Mexico. Results for the present study indicate that dietary inclusion of legumes, hay of good quality and sorghum grain for post-weaning calves may effectively reduce the need for supplementation with commercial concentrates.

The dietary addition of legumes for weaned calves was expected to sustain growth rates near 0.50 kg/d due to increases in the available MP. Similar growth rates have been observed experimentally when legumes are included in the diets of juvenile animals (Aguirre et al., 2006). However, initial slow growth has been reported during the initial stage (two to three months) of legume feeding with a gradual increase as animal acceptance improved (Aguirre et al., 2006; Tesorero and Combellas, 2003). Several studies indicated that there is a rejection in the intake of legumes during the initial weeks of use (Aguirre et al., 2006; Contreras and Rosciano, 1998; Tesorero and Combellas, 2003) due to antinutritional compounds called tannins[17] (Cannas, 2001; Giner-Chavez, 1996; Ramírez-Restrepo and Barry, 2005). Therefore, in this study *ad libitum* intake of legumes may have been overestimated during the first 2 or 3 mo after weaning, which may be coupled with underestimations after the third month since it has been shown that faster growth may occur after adaptation. Consequently, alternative protein sources (e.g., soybean meal, rice polishings, hays of good quality) might also be included in the diets of post-weaned heifers, especially right after weaning, to achieve desired BW gains and to reduce the time delay to puberty. However, as the acceptance of legumes in the diet of calves is improved, better growth may be expected, which may reduce the need for commercial supplementation and thus reduce rearing costs.

6.1.2 Feeding sugar cane and legumes during critical seasons

The animal's performance after 10 mo of age was undoubtedly restricted by bottlenecks in dry matter intake coupled with low forage quality. Such dietary constraints were identified from 10 mo of age until the eighth month of gestation. Therefore, a supplementation scheme was suggested to increase dry matter intake and sustain moderate average growth of about 0.35 kg/d in critical seasons. To achieve this target, local cropped forages like sugar cane and legumes were selected to supply the required nutrients for desired growth rates during the low rain season.

[17] Tannins act as a defense mechanism in plants against pathogens, herbivores and hostile environmental conditions. Generally, tannins induce a negative response when consumed. These effects, like astrigency or a bitter or unpleasant taste, can be instantaneous or can have a delayed response related to antinutritional/toxic effects (Giner-Chavez, 1996).

Table 14 shows amounts of supplementation required from sugar cane and legumes. The total amount of each feedstuff varied considerably by season of birth. For example, the need for more supplementation was predicted for heifers born during the low rain season since they experienced 6 mo of nutrient (feed intake) deprivation during their rearing (Appendix Table 11.4), whereas animals born in the late rain season were expected to require less sugar cane/legume supplementation because of the better quality forage supplies after ten months of age (Appendix Table 11.2).

Table 14. Diet summary required for heifers after ten months of age by season of birth to obtain a target body weight gain about 0.35 kg/d during subsequent seasons of low rain.

Birth season	Sugarcane, total DMI, kg	Legume, total DMI, kg
Early rains	260	100
Late rains	185	55
Scarce rain	225	90
Low rain	315	120

The proportions of sugar cane/legume included in the diets of these animals were approximately six parts of sugar cane to four parts of legumes. Young animals received more protein from legumes than older ones. In general, the supplemental diet had about 2.5 Mcal/d of ME with protein contents that varied from 89 to 72 g/d of MP per kilogram of the mixed sugar cane/legume diet (for heifers at 11 mo and in the late stage of pregnancy, respectively).

Table 15 shows the average daily gain at different physiological stages of development for heifers supplemented with sugar cane/legume during the low rain season. The growth rates during the prepubertal period averaged 0.48 kg/d, which is 25% more than those predicted with the typical management during the season of low rain (0.38 kg/d). Postpubertal growth rates were expected to be about 20% higher when heifers were supplemented in the season of low rain; average growth increased from 0.34 to 0.40 kg/d (daily gain averaged across all seasons). Once pregnant, heifers supplemented with sugar cane/legumes sustained daily gains near 0.36 kg/d, which represents a growth rate increase of about 150% compared to the average daily gain of pregnant heifers receiving typical management. In general, the daily gains predicted from 10 mo of age until the eighth month of pregnancy for supplemented heifers were about 0.40 kg/d, which is 25% more than that expected in GGAVATT-Tepetzintla herds (0.31 kg/d).

Table 15. Average daily gains of management groups of heifers born in the four seasons of the year and receiving sugarcane/legumes supplementation during the low rain season.

Season of birth	Average daily gains (kg/d)		
	From 10 mo to puberty	Puberty to conception	Conception to final month of gestation
Early rains	0.47	0.39	0.38
Late rains	0.52	0.37	0.39
Scarce rain	0.46	0.43	0.36
Low rain	0.46	0.43	0.31

Strategic supplementation with sugar cane/legumes during the low rain season had considerable impacts on the duration of each physiological stage of development. Heifers were predicted to reach puberty (280 kg; 50% MBW) three months younger (15 mo) than the average reported for typical GGAVATT management (18 mo). Conception was predicted at 21 mo of age on average, which is expected to result in first calvings eight months earlier than under typical management. The conception weight for these modestly accelerated growth rates averaged 358 kg (65% MBW), resulting in BW 20 kg lighter at mating than those expected under typical management. Average growth rates for heifers receiving alternative diets were about 0.47 kg (from birth to conception). These results are consistent with those reported by

González-Stagnaro et al. (2006), where heifers with ADG >0.45 kg/d might conceive at about 65% of their MBW.

6.1.3 Energy constraints in the final month of gestation

Based on findings affecting GGAVATT-Tepetzintla heifers during late gestation, especially in the final month, the amount of energy from sorghum grain required to alleviate this deficit was estimated. These amounts of feed (energy) are those that would be required to achieve desired BW and tissue reserve status at parturition (i.e., BCS $\geq$3.0).

Dietary energy balances during the final month of gestation, when only forage is fed, were about -3.4, -5.0, -10.2 and -2.4 Mcal ME/d for the early, late, scarce and low rain seasons, respectively. If these dietary balances were not supplemented, the BW losses of heifers in late gestation would be about 0.74, 1.10, 2.20 and 0.53 kg/d during the seasons of early, late, scarce and low rain. To avoid such losses, energy from sorghum was utilized to supply the increased fetal energy demand (6.1 Mcal ME/d). The quantities of sorghum grain required during the late and low rain season were about 60 and 65 kg, respectively (Appendix Table 11.2 and 11.4). Heifers born in the early and scarce rain seasons needed 40 and 100 kg of sorghum grain, respectively (Appendix Tables 11.1 and 11.3). Heifers born in the low rain season (Appendix Table 11.4) needed about 35 kg of sorghum to preclude tissue catabolism. However, to this group of animals 30 kg extra were supplied to achieve 80% of MBW.

In general, accelerating the heifers' growth and increasing body size and body tissue reserves may be desirable because they imply shortened durations to reach puberty, conception and, consequently, first calving. A greater proportion of adipose tissues might also be beneficial to restore postpartum ovarian cyclicity during the second and subsequent pregnancies and lactations. However, all these possibilities are dependent upon post-natal and pre-weaning nutrition as well, since an animal will not grow if not provided the correct nutrition.

6.3 Calve growth management options in GGAVATT-Tepetzintla

Calves in GGAVATT-Tepetzintla herds, after nursing their dams for the first two or three days of life, are separated and raised artificially with 5 or 6 kg of milk replacer daily, until three months of age. This management generally allows growth rates of about 0.65 kg/d (GGAVATT-Tepetzintla, personal communication), which may be acceptable for DP animals. Generally, good growth rates can be achieved if enough nutrients and the proper balance of nutrients are provided to the calf after the maintenance is met (Van Amburgh and Drackley, 2005). As calves grow, the nutrient requirements for maintenance gradually increase, which may constrain the growth rates if the amount of nutrients supplied in the milk replacer are not increased, which commonly occurs in GGAVATT-Tepetzintla herds.

The feeding costs during the pre-weaning period are relatively expensive compared with the post-weaning period. If we account for the amount of milk replacer consumed until the third month of age, this sums to about 50 kg (DM basis), which at a cost of $1.83 per kilogram results in about $91.50. The trend over the last 20 yr has been towards weaning heifers as early as possible. Several reasons have been identified to reduce the number of days to milk-feed calves. Among the incentives the most important is that the cost of feed energy in whole milk or milk replacer is greater than the energy cost in dry feed, in addition to liquid feeding requiring more labor to administer ().

A management scheme that could be used in GGAVATT-Tepetzintla is reduce age at weaning to 6 or 8 weeks of age, by increasing the density of nutrients contained in the milk replacer. For example, if the amount of nutrients offered daily in the milk replacer is increased a 50%, the costs of feeding at 6 or 8 weeks will be about $37.80 and $50.40, respectively. The extra nutrients during early stages of growth could be expressed in greater daily gains (Van Amburgh and Drackley, 2005). Moreover, calves can be successfully weaned onto dry feed when eating 0.5 kg/day of concentrates, which normally occurs around 6 weeks of age (Moran, 2002). Weaned calves should weigh at least double of their birth weight and be seen ruminating. The extra savings from reduced days consuming milk could be used to purchase commercial concentrate or starter of good quality in order to assure rapid rates of calf growth after weaning.

6.4 Economic appraisal of management to achieve earlier age at first calving

A simple partial budgeting analysis of marginal costs provided an approximation of the potential economic incentives to implement alternative dietary strategies in GGAVATT-Tepetzintla replacement herds. The strategy involves supplementation with good quality harvested forages at times of forage scarcity and for certain physiological stages of development when dietary nutrient intakes need to be greater. Therefore, the economic assessment was focused on the ΔIOFC using typical GGAVATT dietary management and alternative management, where heifers would receive the above mentioned dietary support from weaning until first calving.

Table 16 shows the amount of each feed consumed, FC and ΔFC from weaning to calving (calving at different ages) for heifers under traditional and improved nutritional management. The FC for heifers calving at 30 mo in the alternative management was about \$479, which was \$80 less (ΔFC) than for heifers calving at 38 mo under typical management. Differences in feeding costs were attributed to the extra feeding days (grazing; 240 days) for maintenance in the traditional rearing system because of the slow growth predicted with this management. These findings agree with those reported in temperate countries, where it has been demonstrated that it is economically more efficient to feed replacement heifers at a high plane of nutrition and reduce the number of days to calving (Cady and Smith, 1996; Pirlo et al., 2000; Tozer and Heinrich, 2001).

A sensitivity analysis was carried out to examine whether it is more profitable reduce the days of maintenance even when the prices of seasonal forages were reduced to the half of the assumed value. The ΔFC when the assumed cost of forage production is \$0.035 rather than \$0.07 per kg, is much lower, \$11. When the forage cost is assumed to be \$0.02 per kg, feed costs savings were negligible under alternative management.

To evaluate further the economic impact of AFC (30 *vs*. 38 mo), the change in the present value of IOFC was calculated. In addition to the change in the present value of feed costs, the change in IOFC depends on the changes in the present value of milk revenue from first and third lactation milk sales. The PV of IOFC of heifers receiving typical and alternative dietary management was calculated under the assumption of similar milk yields, which probably understates the expected changes in profitability due to alternative management because of better BCS and heavier BW at calving.

Table 16. Feeding management costs ($/US[a]) in GGAVATT-Tepetzintla herds for heifers reared under typical and alternative dietary management.

	Traditional	Alternative
Amount of each feed (kg)[a]		
Seasonal grasses	7050.0	5094.0
Legumes	0.0	183.0
Hay of improved forage	0.0	198.0
Sugarcane	0.0	252.0
Sorghum	0.0	135.0
Commercial concentrate	210.0	0.0
Total value of each feed ($)[b]		
Seasonal grasses (increased price)	493.5	356.6
Legumes	0.0	27.5
Hay of improved forage	0.0	21.8
Sugarcane	0.0	37.8
Sorghum	0.0	35.1
Commercial concentrate	65.1	0.0
Total	558.6	478.8
Difference, Alternative less Traditional	--	-79.8
Total value of feed ($), lower forage cost[c]		
Seasonal grasses	246.8	178.3
Total feed Cost	311.9	300.5
Difference, Alternative Less Traditional	**--**	-11.4

[a] Total amount for each feedstuff predicted by the CNCPS from weaning to calving for heifers under traditional and alternative dietary management.

[b] The cost of each feedstuff estimated from the amount consumed and the assumed price in Table 7

[c] Costs of feeding when the value of seasonal grasses is reduced 50%

Heifers calving at 30 mo increased PV of IOFC by $82 at the end of first lactation compared to traditional management ($35 *vs*. $-47) and by $117 at the end of 3-lactations ($883 *vs*. $766). Through the end of the first lactation, the reduction in the PV of feed costs constitutes about 70% of the larger IOFC under alternative management. About half of this difference is due to changes in the present value of milk revenues ($60) at the end of three lactations. According to the CIMMYT, producers are more likely to show interest in technologies with which they are already somewhat familiar if the MRR is at least 0.5. Unlike many technologies, the change in costs is negative in this case because PV of the costs (feed costs) are reduced. Thus, the calculated MRR would be 81.49/-57.77 = -1.41. When the MRR < 0, it is usually because the change in net income is negative, so this is not consistent with the usual interpretation of the MRR. However, farmers might be expected to be more interested in technologies or management practices that both increase the PV of revenues and reduce the PV of costs. The expected outcome under these baseline assumptions suggests that there is an economic incentive for farmers to reduce the AFC and improve the general condition of replacement heifers by investing in better feeding management (production of better quality harvested forages).

The change in PV of IOFC is much smaller when lower forage costs are assumed. Heifers calving at 30 mo increased the PV of IOFC by $27 at the end of the first lactation compared to the traditional management ($191*vs*. $164) and of $63 ($1,040 *vs*. $977) at the end of 3-lactations (Table 17). Differences in the PV of feed costs under assumed lower forage costs are minimal; nearly all of the difference in the PV of IOFC in this case is due to changes in the PV of milk revenues. This analysis shows that lower costs of seasonal forages reduce the incentives for earlier AFC. Moreover, if the cost of seasonal forages is assumed to be of $0.02 per kg of DM, the

Table 17. Present value from milk sales from first and three-lactations, and present value for incomes over feed costs[a] for heifers calving at 30 and 38 mo of age under traditional and alternative nutritional management.

	Traditional	Alternative	Difference
Baseline Analysis			
End of First Lactation			
Present Value Milk Revenues, $	434.47	458.19	23.72
Present Value Feed Costs, $	481.09	423.32	-57.77
PV IOFC, $	-46.62	34.87	81.49
End of Third Lactation			
Present Value Milk Revenues, $	1,247.05	1,306.71	59.66
Present Value Feed Costs, $	481.09	423.32	-57.77
PV IOFC, $	765.96	883.39	117.43
Seasonal forage cost reduced to $0.035/kg			
End of First Lactation			
Present Value Milk Revenues, $	434.47	458.19	23.72
Present Value Feed Costs, $	270.29	267.14	-3.15
PV IOFC, $	164.18	191.04	26.87
End of Third Lactation			
Present Value Milk Revenues, $	1,247.05	1,306.71	59.66
Present Value Feed Costs, $	270.29	267.14	-3.15
PV IOFC, $	976.76	1,039.57	62.81
Seasonal forage cost reduced to $0.02/kg			
End of First Lactation			
Present Value Milk Revenues, $	434.47	458.19	23.72
Present Value Feed Costs, $	179.95	267.14	20.26
PV IOFC, $	254.52	257.98	3.46
End of Third Lactation			
Present Value Milk Revenues, $	1,247.05	1,306.71	59.66
Present Value Feed Costs, $	179.95	200.21	20.26
PV IOFC, $	1,067.10	1,106.50	39.40

[a] Price of seasonal grasses = $0.07

change in PV of IOFC for heifers calving at 30 mo would be $3 at the end of the first lactation and $39 at the end of 3-lactations (Table 17).

This implies that the production cost of forage is an important component of evaluating the changes in profitability with earlier calving, and this variable should be given greater emphasis for any given farm evaluating this choice. However, the milk yield assumed for heifers calving at 30 mo with a BCS = 3 and heifers calving at 38 mo with a BCS = 2.5 in this evaluation was assumed to be equal. This undoubtedly understates the expected differences in milk yields from heifers that are heavier and with greater BCS (Absalon-Medina, 2008), which would positively affect the change in PV of IOFC even when the forage cost is reduced to $0.02 per kg of DM.

In addition to the changes in the PV of IOFC, GGAVATT-Tepetzintla members are expected to obtain additional economic benefits that were not estimated in this study. These include increases in the expected average productive life by calving at a younger age, which may result in more revenues from calf sales and milk production. Improved weights at calving may lead to fewer open days after calving and greater salvage values from heavier cows at culling. Moreover, decreasing AFC may allow reductions in the replacement herd size, which will save expenditures on food and that savings could be used to feed the milking herd. In conclusion, GGAVATT-Tepetzintla farmers, and probably many other GGAVATTs or dual-purpose herd owners in northern Veracruz, apparently have larger economic incentives to shorten the rearing days and increase the body weight at calving by improving the nutritional management through strategies similar to those suggested in this study.

Fundamentally important to this dietary management strategy is to know the quality of forages and other feeds (i.e., analysis and monitoring of chemical composition), identify management groups of heifers that differ in their nutritional requirements and, in addition, use an effective nutrition tool like the CNCPS model to sensitively manage growing animals. The outputs derived from this study correspond to a monitoring protocol throughout physiological stages of development for heifer management groups that are defined by forage season of birth, and phases of physiological maturation.

7.0 Conclusions

This GGAVATT-Tepetzintla case study clearly identified important biological (protein and energy) and management limitations affecting the performance of dual-purpose replacement heifers in northern Veracruz. It is believed to be the first published study in a tropical environment to systematically evaluate interactions among expected body weights, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances for specified heifer management groups. Heifer management groups defined by three physiological stages of development (prepuberty, postpuberty and gestation) and four forage seasons of birth (early rains, late rains, scarce rain and low rain) were evaluated from weaning to first parturition. This structured analysis involved 124 simulations to identify opportunity windows for GGAVATT dietary management that would alleviate nutritional bottlenecks to reduce age at first calving of replacement females in dual-purpose herds.

Results showed that the CNCPSv6 model can accurately predict typical growth scenarios for GGAVATT-Tepetzintla replacement females. Findings revealed important weaknesses, or bottlenecks, affecting growth and development of heifers including ages at puberty, conception and first parturition. The body weights and ages observed in the GGAVATT heifers by physiological stage of development were similar to the average CNCPS-predicted body weight outcomes, which were based on approximations of the chemical composition of feeds and typical feeding management. This study clearly demonstrated that the CNCPS is a viable tool for identifying nutritional constraints and for monitoring growth and the development of heifers.

Analysis of typical, or baseline, management scenarios revealed important vulnerabilities during a heifers' development: chronic protein deficiencies among weaned calves until approximately 10 mo of age and impeded growth during the season of low rain. Regardless of season of birth, post-weaned heifers in GGAVATT-Tepetzintla herds experience negative protein balances. Restrictions in dietary MP reduced the daily gains of young heifers, resulting in body weights below 200 kg at 10 mo of age. Energy deficiencies begin to arrest growth when heifers are 10 mo of age. Negative dietary energy balances delayed reproductive performance and age at calving. When negative energy balances were predicted, the pool of tissue reserves available for milk synthesis was depleted, thus jeopardizing future cow performance. Therefore, heifers under typical rearing conditions are frequently old and underweight for their age at calving, which limits their feed intake, milk production and productive lifetimes.

Based on these bottlenecks, opportunity windows were identified, a management strategy using low cost, locally-produced feeds, especially available forages (e.g., grass hay, sugarcane, legumes), to reduce heifer vulnerability. This approach was aimed at feasibly assuring growth rates to achieve younger ages and desired body weight and tissue reserves at first calving. The modest dietary inclusion of protein sources like legumes, complemented with sorghum grain and hay of good quality, increased the MP available for growth in young animals, resulting in a BW of about 210 kg by 10 mo of age. The addition of supplementary forages, sugar cane and tree legumes, into the diets of heifers older than 10 mo, and only during the most restrictive forage season of the year (low rain), substantially improved average growth rates (from 0.29 to 0.41 kg/d), primarily by avoiding typical weight losses from nutrient depravation. Increased growth rates during the seven month period following weaning and in the low rain season resulted in average ages at puberty and conception of 15 and 21 months, respectively. These ages are 3 mo and 8 mo younger than typically occurs in GGAVATT herds. Furthermore, energy supplementation in the final month of gestation averted the typical catabolism of adipose tissue reserves, thus increasing the energy pool in support of greater milk yields in first lactation (see Absalon-Medina, 2008).

The partial budgeting analysis of marginal costs showed that it is economically rational, and likely more profitable, to calve heifers at a younger age than to delay AFC to 38 mo. Under the assumptions of this study, the FC for heifers calving at 30 mo (alternative management) was about $479, which was less than for heifers calving at 38 mo (alternative management) with about $80 lower feed costs per animal. In addition, heifers calving at 30 mo were predicted to obtain $82 higher PV of IOFC by the end of first lactation compared to traditional management ($35 *vs*. $-47); and $117 greater PV of IOFC from a 3-lactation lifetime ($883 *vs*. $766).

When seasonal forage costs are less, the incentives for earlier age at first calving diminish considerably. However, the assumed milk production for heifers calving at 30 mo with a BCS = 3 and heifers calving at 38 mo with a BCS = 2.5 in this evaluation was treated as equal, which undoubtedly understated the expected difference in milk revenue for heifers that are heavier and with larger tissue reserves (better BCS). In addition to changes in the PV of IOFC, GGAVATT-Tepetzintla members are expected to obtain additional economic benefits that were not considered in this study. These include greater revenues from more calf sales and more milk production from cows calving first at an earlier age. Better BCS at calving may lead to fewer open days and greater salvage values from heavier cows at culling, reductions in the replacement herd size, which would reduce expenditures on feed that could be invested in the milking herd.

In conclusion, GGAVATT-Tepetzintla farmers, and probably many other dual-purpose herd owners in northern Veracruz, undoubtedly have large economic incentives to reduce the age, and increase body weight and condition score at first calving of replacement heifers by implementing nutritional strategies like those considered in this study. To achieve this goal, it is essential to know the quality of forages and other feeds (i.e., analysis and monitoring of chemical composition), identify management groups of heifers that differ in their nutritional requirements and, in addition, use an effective nutrition tool like the CNCPS model for the sensitive management of growing animals.

APPENDIX

Appendix 1

Estimated values for different productive parameters of cattle reared in the Mexican tropics (Román-Ponce, 1981).

Items	Value
Birth weight, kg	28
Mortality, %	10
Weaning weight, kg	150
Steers culling age, mo	36
Steers weight at culling, kg	430
Carcass, %	52
Conception rate, %	40
Age at first calving, mo	40
Calving intervals, mo	16
Milk yield per lactation, kg	450
Cow’s productive lifetime, yr	4
Culling rate, %	15

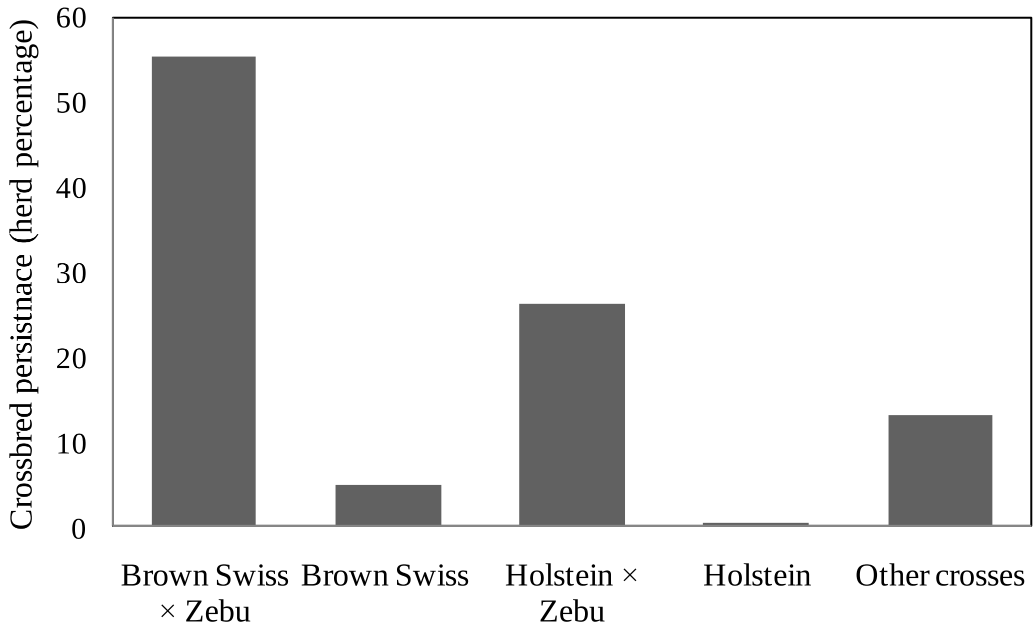
Appendix 2

Age composition of the cattle population reared in the Mexican tropics (Román-Ponce, 1981).

Item	Percentage (%)
Bulls	2
Cows	29
Bulls and cows for culling (more than 3 years)	14
Heifers (2 to 3 years)	14
Steers (2 to 3 years)	16
Heifers (1 to 2 years)	13
Calves (less than 1 year)	12

Appendix 3

Histogram depicting the average herd inventory for GGAVATT-Tepetzintla owners. More than 50% of the animals owned by this GGAVATT are crosses of Brown Swiss × Brahman (González-Ortega et al., 2007).



Appendix 4

Nutritional constraints and management options for tropical dual-purpose replacement herds in the low Huasteca region of Veracruz (adapted from Reynoso-Campos et al., 2004; Absalon-Medina, 2008; Baba, 2007).

Constraints	Actions to resolve the constraints	References
Lack of nutritional management information	Systematic evaluation of nutritional limitations	Reynoso-Campos et al. (2004)
Extended age at first calving	Accurate estimation of animal nutrient requirements	Juárez et al. (1999) Absalon-Medina (2008)
Low body condition score (BCS)	Chemical analysis of forages and diet offered to animals	Baba (2007)
Low quality forages for heifers	Forage management	Juárez et al. (2002)
Energy and protein limitation	Identifying optimal age at grazing of managed forages	Rueda et al. (2003)
Low digestibility of grasses	Having an adequate stocking rate per season of the year	
Poor management of replacement females after weaning	Increasing nutritional inputs to accelerate growth and reduce average ages at conception and first calving.	Heinrichs et al. (1998) Van Amburgh (2004, 2005) González-Stagnaro (2007)
Grouping animals	Grouping animals by weight or physiological stage	
Growth targets	Assessing target growth rates by physiological stage	
Record keeping	Keeping records to evaluate growth rates and compensating for nutrient scarcity during critical seasons	
High cost of supplement diets	Systematic evaluation of alternative forages	Urbina (1991)
Lack of knowledge about alternative forage to offset constraints of low quality forages.	Legumes (tree) Forages (cutting forages)	Juárez et al. (2002) Rueda et al. (2003) Shelton (2004)
Soil testing and fertilization rarely used.	Soil and pasture analysis to identify nutrient stock in the grazing system An adequate animal stocking rate with careful fertilization may increase dual-purpose cattle productivity.	Rueda et al. (2003)

Appendix 5

Number of heifers required to maintain a 100-cow dual-purpose herd at different rates of replacement and ages at first calving considering a 10% heifer death loss. Adapted from Cady and Smith (1996)

Age at first calving (mo)	Replacement rate (%)				
	10	**15**	**20**	**25**	**30**
24	22	33	44	55	66
28	26	39	51	64	77
32	29	44	59	73	88
36	33	50	66	83	99
40	37	55	74	92	110
44	40	61	81	101	121

Appendix 6

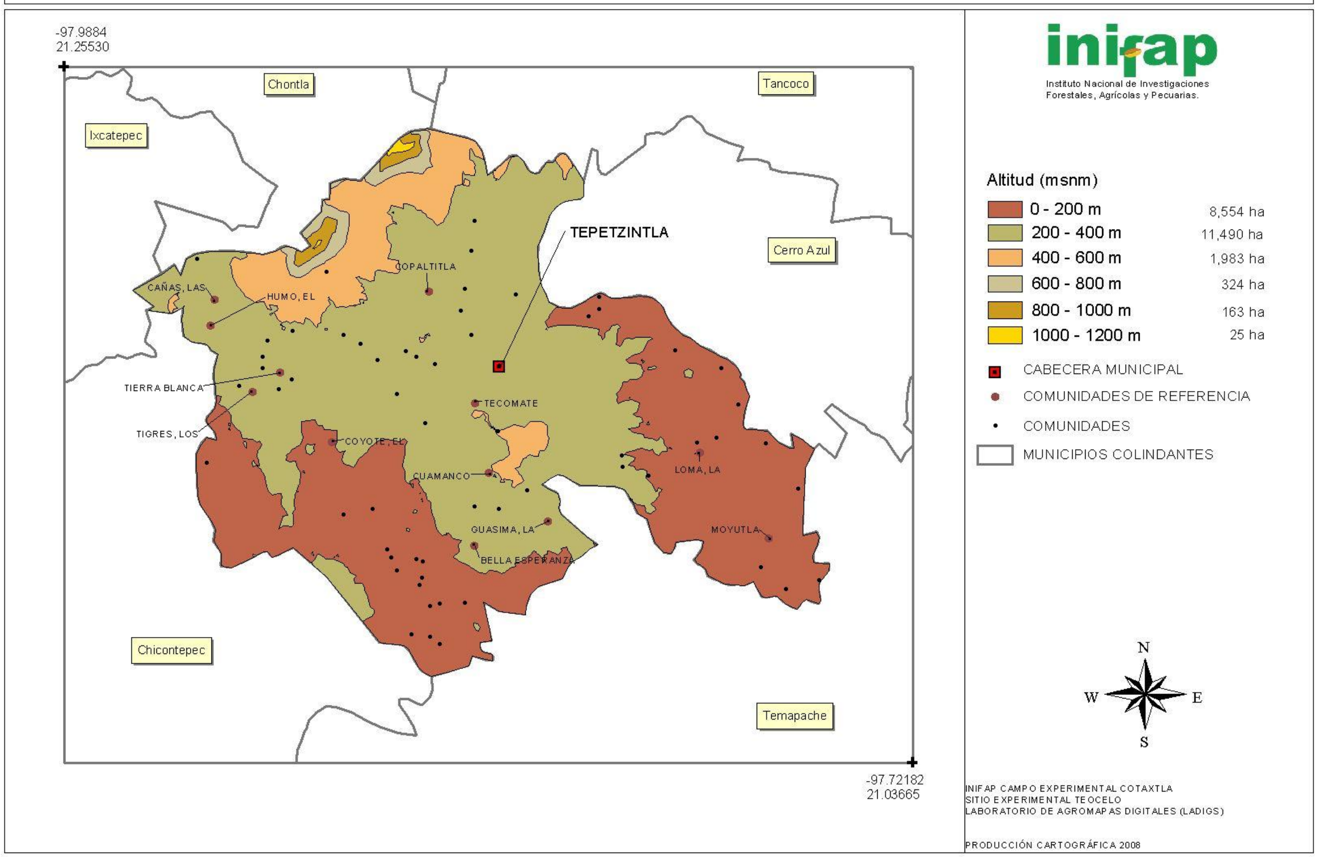
Average monthly temperature (T), night temperature (Tmin), relative humidity (RH), rainfall (RF), and wind speed (WS) for the warm-humid climatic zone of the municipality of Tepetzintla, Veracruz from 1971 to 2000 (Estación meteorológica no. 3026, Tlacolula ETA 175, Comisión Nacional del Agua).

Variable	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Temperature (°C)	16.6	17.8	21.9	25.0	27.6	27.3	26.7	27.2	25.5	23.6	19.5	17.1
Minimum temperature (°C)	11.7	12.5	15.8	18.7	21.4	21.9	21.8	21.7	20.4	18.5	14.5	12.5
Relative humidity (%)	78.3	78.2	77.2	77.0	76.0	76.2	77.0	76.8	78.1	78.7	78.1	78.4
Rainfall (mm)	50.7	61.1	44.0	56.0	75.5	501.1	195.7	150.5	261.0	90.6	42.2	60.8
Wind speed (kph)	5.0	5.0	6.0	6.0	6.0	6.0	5.0	4.0	5.0	5.0	5.0	5.0

Appendix 7

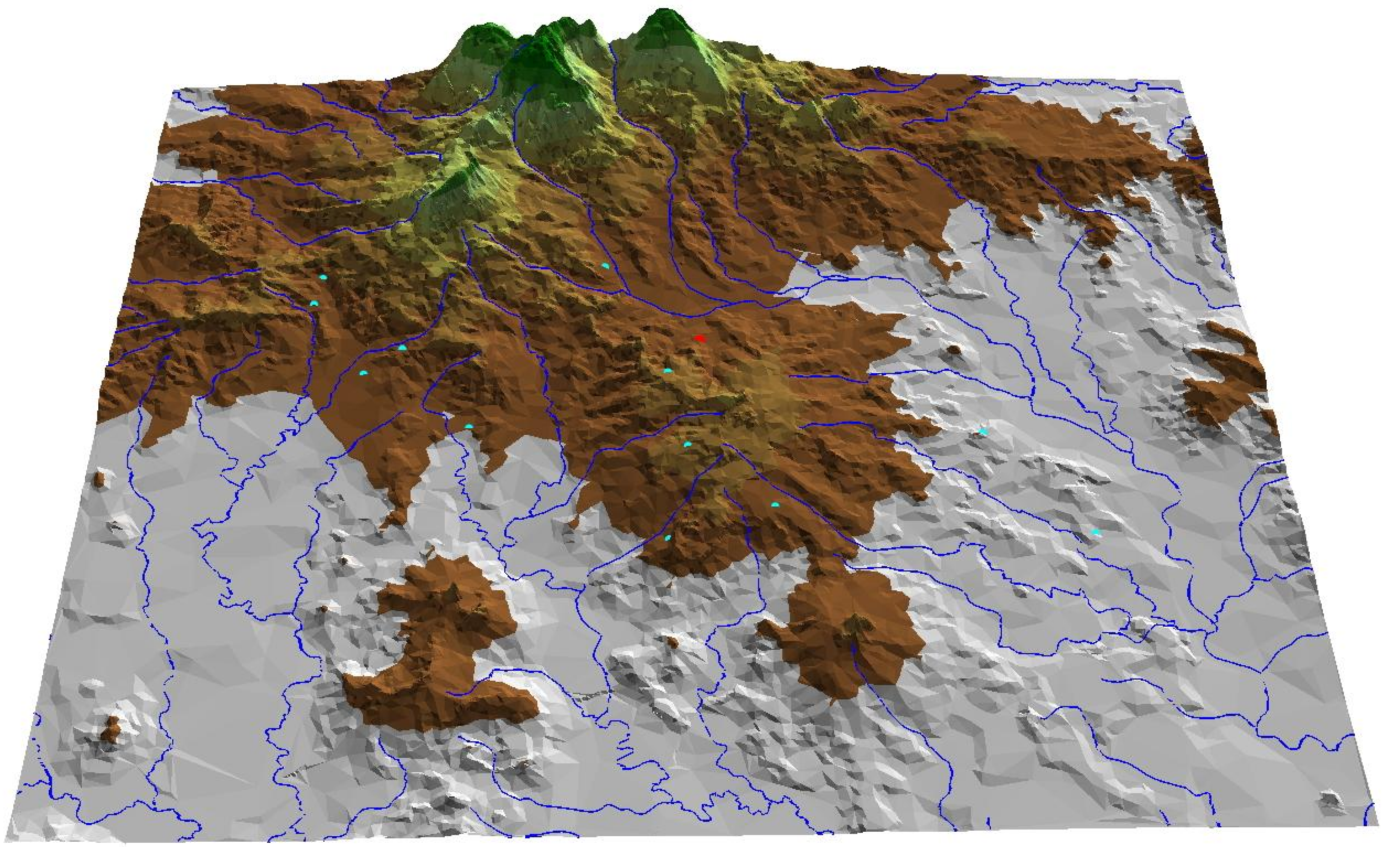
This series of maps includes: altitudes, climate, rainfall distribution, type of land, temperatures, land use, rivers, slopes and locations. Courtesy: M.C. Gabriel Díaz Padilla, INIFAP Campo Experimental Jalapa, Sitio Experimental Teocelo. Laboratorio de Agromapas Digitales (LADIGS). Producción cartográfica 2008.

Estratos altitudinales en el municipio de Tepetzintla, Veracruz.

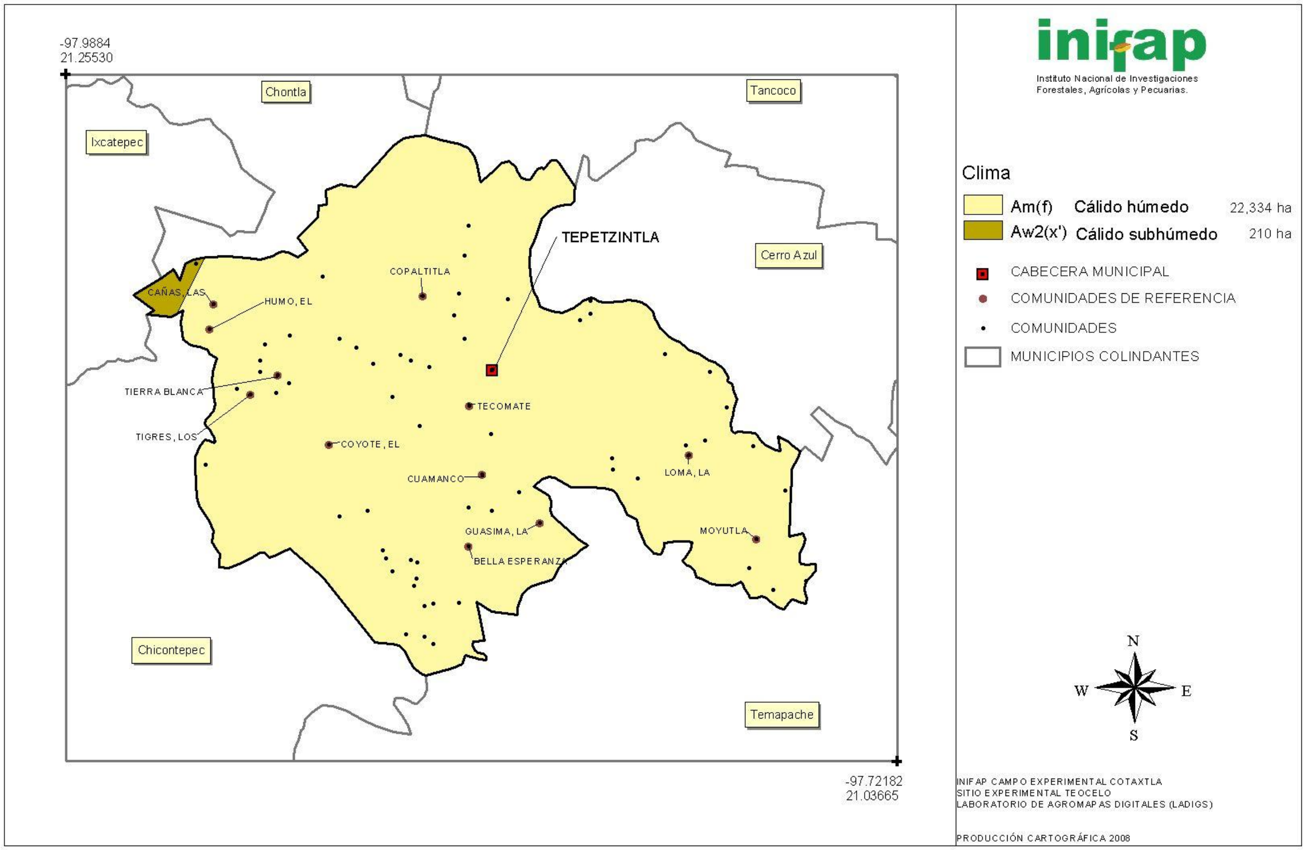


inifap

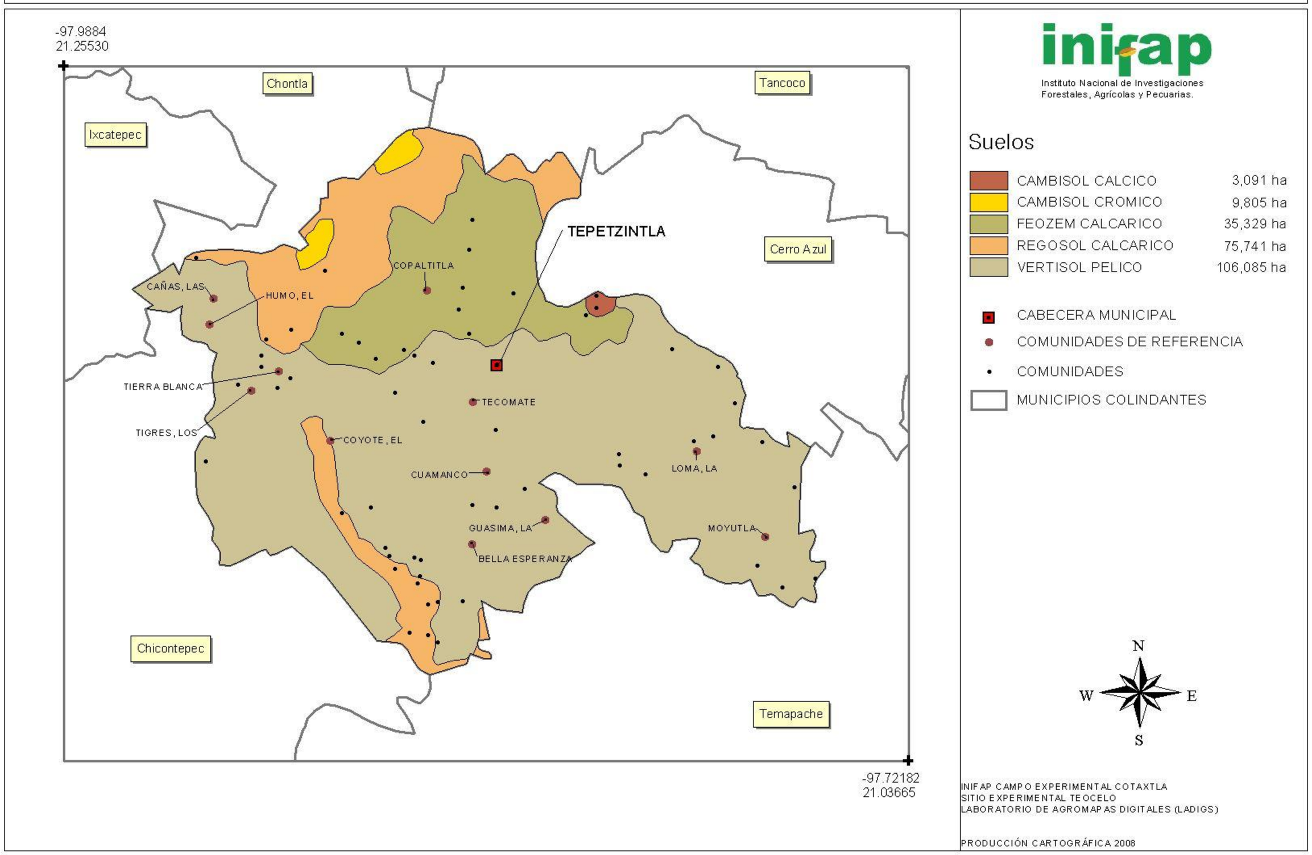
Instituto Nacional de Investigaciones
Forestales, Agrícolas y Pecuarias.



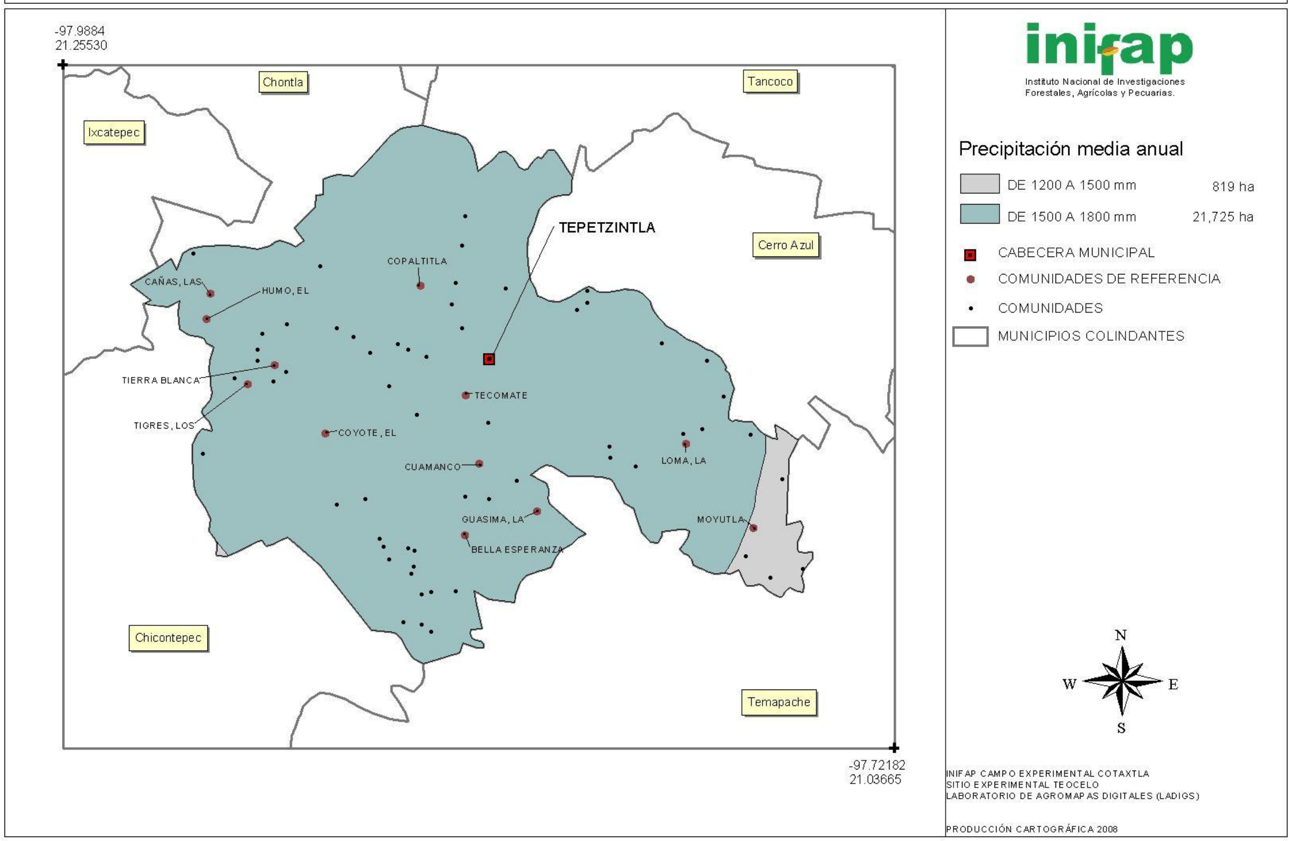
Clima en el municipio de Tepetzintla, Veracruz.



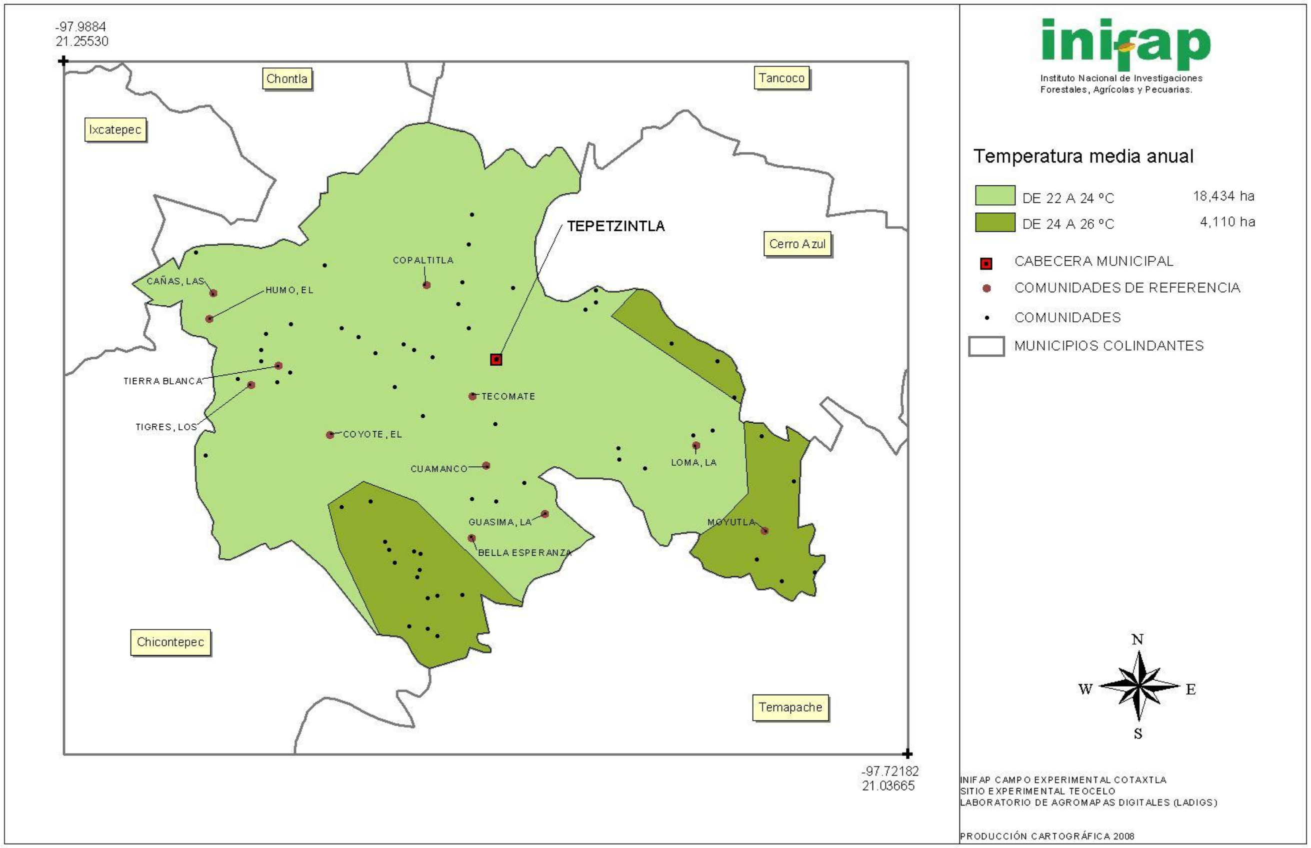
Principales unidades de suelo en el municipio de Tepetzintla, Veracruz.



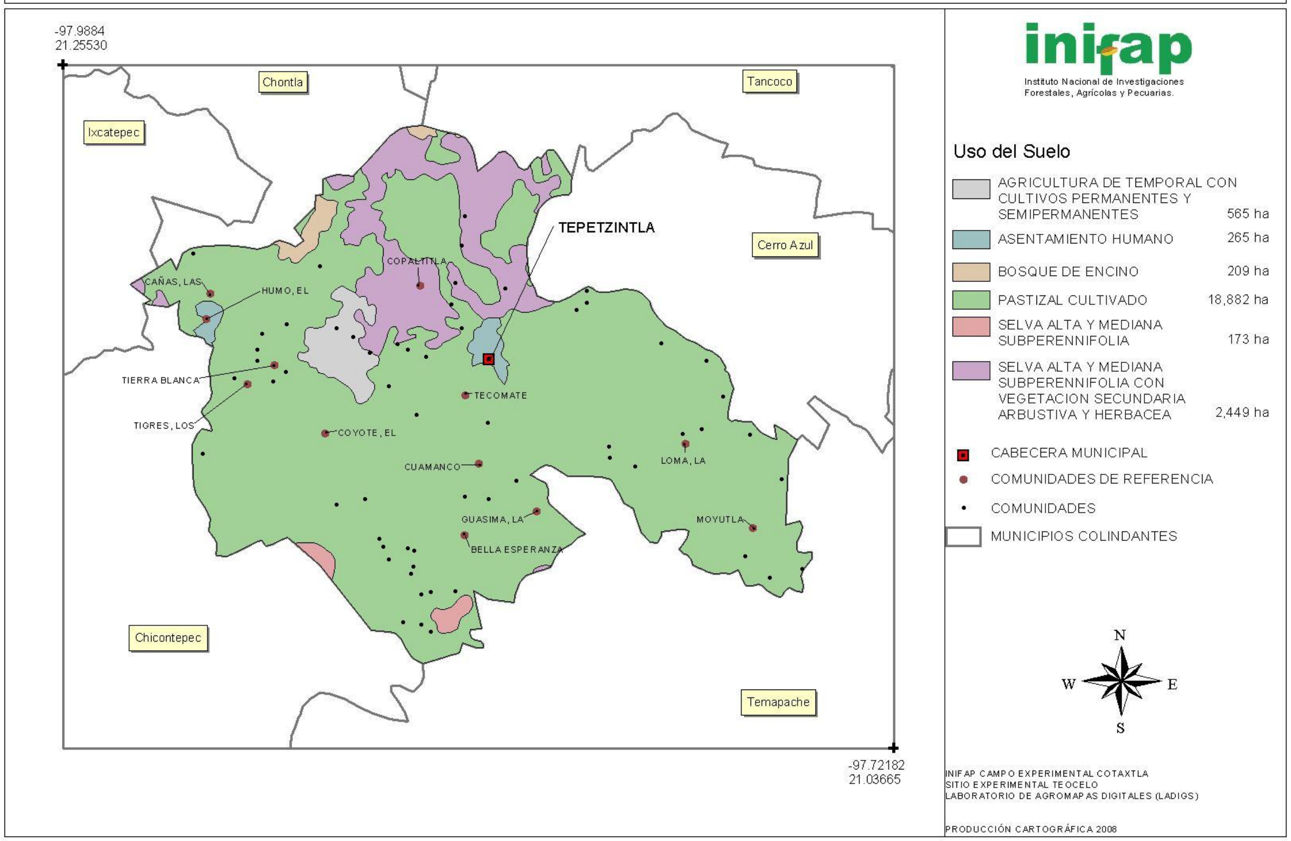
Precipitación media anual en el municipio de Tepetzintla, Veracruz.



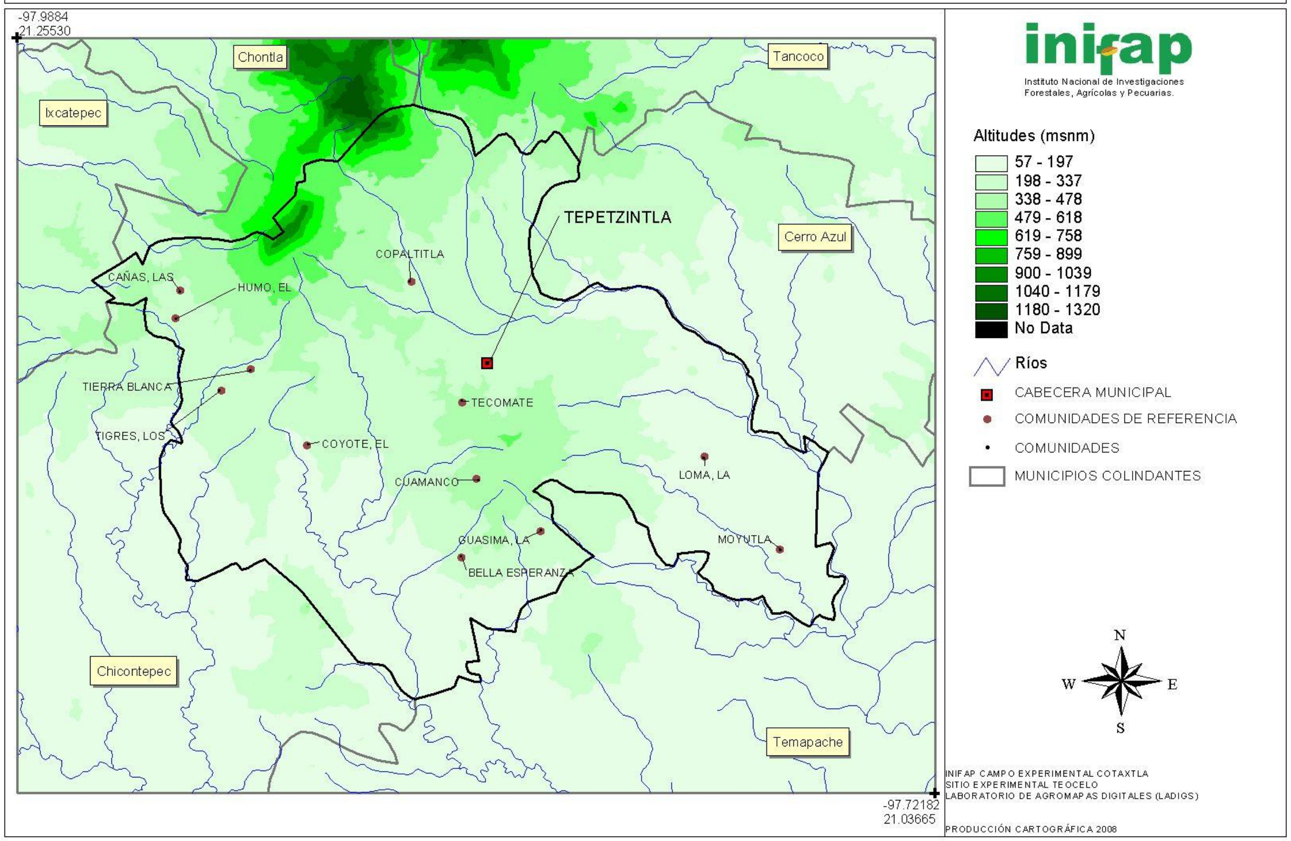
Temperatura media anual en el municipio de Tepetzintla, Veracruz.



Uso del suelo en el municipio de Tepetzintla, Veracruz.

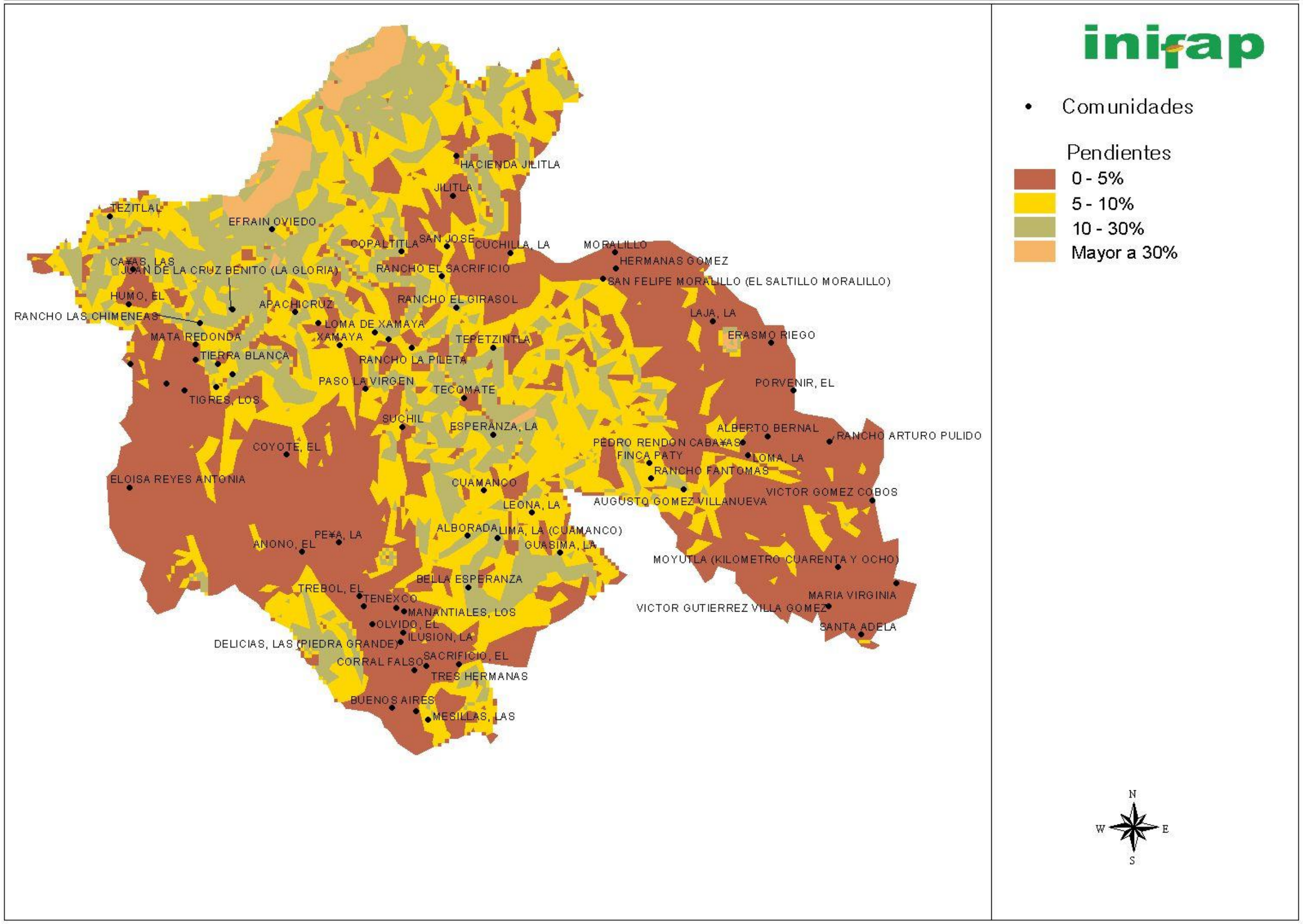


Red hídrica y topografía en el municipio de Tepetzintla, Veracruz.

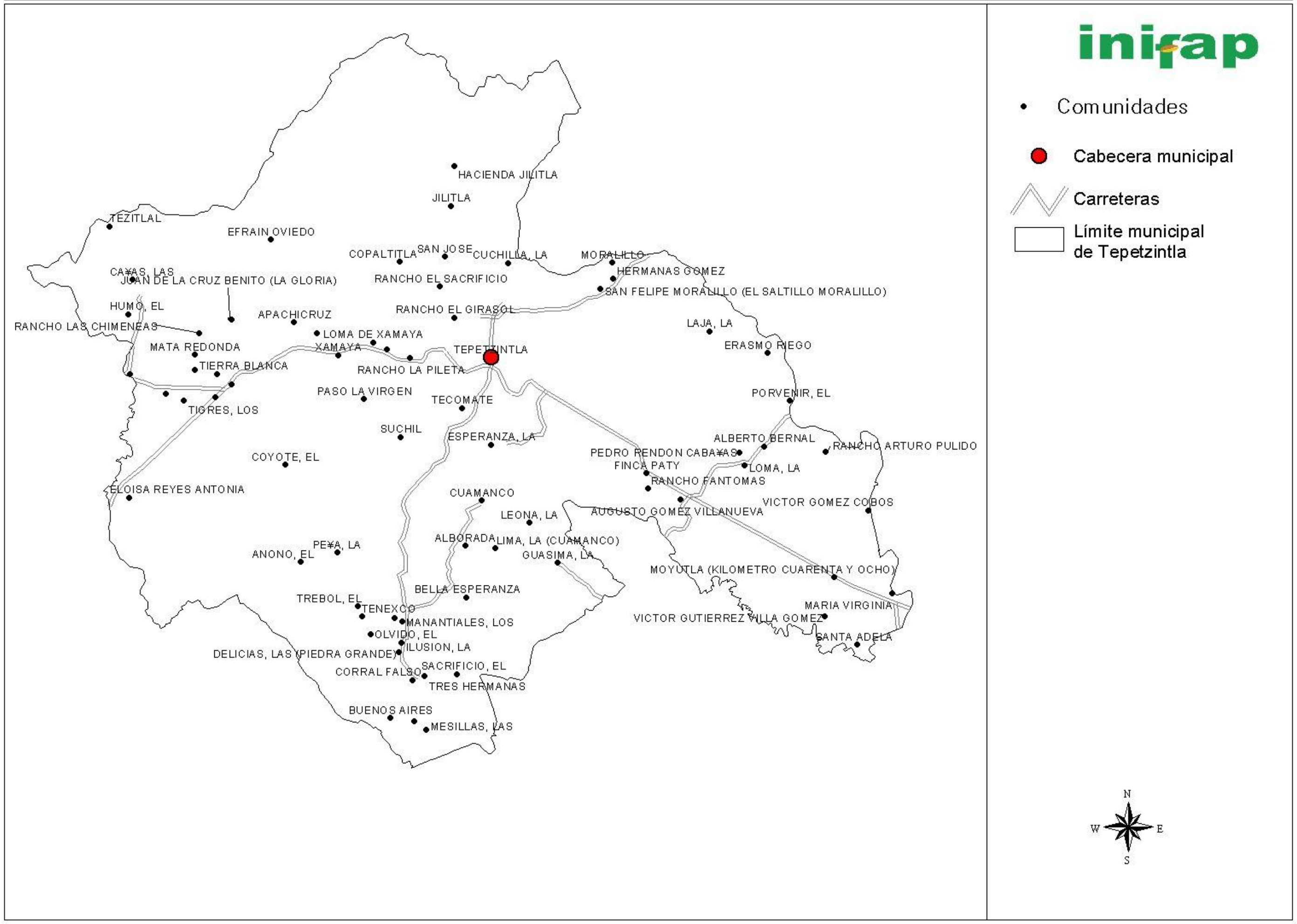


157

Pendientes en el Municipio de Tepetzintla, Veracruz



Localidades en el Municipio de Tepetzintla, Veracruz



158

Appendix 8

Contrasting environmental conditions and physical activity (walking distances) to evaluate the sensitivity of Cornell Net Carbohydrate and Protein System predictions of animal energy requirements for maintenance.

Variables	Season		
	Early rain	Scarce rain	Thermoneutral environment
Temperature, °C	27	18	20
Humidity (%)	77	78	50
Wind speed, kph	20	23	1
Sun exposure, h/d	6[a]	10	0
Minimum night temperature, °C	21	13	15
Time standing, h/d	14[b]	18	0
Daily number of body position changes	6[c]	8	0
Flat distances walked, km/d	1.8	2.7	0
Sloped distances walked, km/d	0.2	0.3	0

[a, b, c] These inputs do not correspond to this particular case because this table intends to represent the ranges of all the values existing for the GGAVATT-Tepetzintla scenario, the actual values were 10, 18 and 8, respectively.

Appendix 9

Assumed daily distances walked for heifers from 10 mo of age until one month prior to calving by season of the year.

Walked distance (km)	Grazing season			
	Early rains	Late rains	Scarce rain	Low rain
Flat	1800	1800	2700	2250
Sloped	200	200	300	250

Appendix 10

Impact of environmental factors and physical activity affecting energy requirements for maintenance.

Values	Body weight (kg)								
	200			300			400		
	Max	Min	Dif	Max	Min	Dif	Max	Min	Dif
Time standing, h/d	0.6	0.5	0.1	0.9	0.7	0.2	1.2	1.0	0.2
Number of body position changes	0.2	0.1	0.1	0.3	0.1	0.2	0.3	0.2	0.1
Flat distances walked, km	0.6	0.4	0.2	0.9	0.6	0.3	1.2	0.8	0.4
Sloped distances walked, km	0.7	0.5	0.2	1.0	0.7	0.3	1.4	0.9	0.5

Appendix section 11

Appendix Table 11.1 Heifers reared in GGAVATT-Tepetzintla herds born in the season of early rains (June 1) receiving improved diets: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty						
	Supplementation				Grazing		
Forage season[a]	L	S	S	N	N	E	L
Heifer age	3 to 5	5 to 6	6 to 9	9 to 10	10 to 12	12 to 14	14 to 15
Forage DMI, kg/d	2.0	2.2	2.2	2.5	4.7	6.2	7.4
Supplement, kg/d	…	…	…	…	…	…	…
Legume, kg/d	0.3	0.4	0.4	0.6	0.6	…	…
Mulato hay, kg/d	0.5	0.7	1.2	1.3	…	…	…
Sugarcane, kg/d	…	…	…	…	0.9	…	…
Sorghum, kg/d	0.4	0.4	0.5	0.5	…	…	…
Total DMI[b], kg/d	3.2	3.7	4.3	4.9	6.2	6.2	7.4
Total dietary energy[c], Mcal ME/d	7.0	8.1	9.5	10.4	12.2	13.2	15.0
Total dietary protein[d], g MP/d	276.0	319.0	374.0	399.0	423.0	478.0	566.0
Initial BW, kg	95	127	143	191	207	230	263
Mean BW, kg	111	135	167	199	219	247	271
Final BW, kg	127	143	191	207	230	263	279
Maintenance requirements[e]							
Energy, Mcal ME/d	4.1	4.8	6.3	6.6	8.6	8.8	9.8
Protein, g MP/d	152.0	181.0	206.0	241.0	317.0	287.0	350.0
Nutrients available for growth[f]							
Energy, Mcal ME/d	2.3	2.8	3.1	3.7	3.3	4.4	5.1
Protein, g MP/d	154.0	156.0	153.0	152.0	113.0	158.0	155.0
Pregnancy requirements[g]							
Energy, Mcal ME/d	…	…	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…	…	…
Energy allowable gain[h], kg/d	0.62	0.58	0.50	0.50	0.38	0.51	0.50
Protein allowable gain[i], kg/d	0.50	0.51	0.55	0.54	0.36	0.62	0.70
Inputted gain[j], kg/d	0.50	0.51	0.50	0.50	0.36	0.51	0.50
Feed energy balance[k], Mcal ME/d	0.6	0.5	0.0	0.1	0.2	0.0	0.1
Required %	98.0	95.0	91.0	91.0	92.0	92.0	95.0
Feed protein balance[l], g MP/d	-42.0	-35.0	-3.0	-12.0	-33.0	8.2.0	43.0
Required %	87.0	90.0	99.0	97.0	93.0	102.0	108.0

Appendix Table 11.1 (continued)

Item	Postpuberty		Gestation (trimester)				
	Grazing		1	2		3	
Forage season[a]	L	S	N	E	L	L	S
Heifer age	15 to 17	17 to 21	21 to 24	24 to 26	26 to 27	27 to 29	29 to 30
Forage DMI, kg/d	7.9	8.5	6.3	8.8	10.2	10.6	7.6
Supplement, kg/d	…	…	…	…	…	…	…
Legume, kg/d	…	…	0.7	…	…	…	…
Mulato hay, kg/d	…	…	…	…	…	…	…
Sugarcane, kg/d	…	…	2.2	…	…	…	…
Sorghum, kg/d	…	…	…	…	…	…	1.3
Total DMI[b], kg/d	7.9	8.5	9.2	8.8	10.2	10.6	8.9
Total dietary energy[c], Mcal ME/d	16.0	16.7	17.9	18.8	20.5	21.2	18.7
Total dietary protein[d], g MP/d	603.0	625.0	583.0	685.0	783.0	811.0	699.0
Initial BW, kg	279	310	351	385	414	426	444
Mean BW, kg	295	331	368	400	420	435	444
Final BW, kg	310	351	385	414	426	444	444
Maintenance requirements[e]							
Energy, Mcal ME/d	10.5	12.5	13.1	12.9	13.6	14.6	12.5
Protein, g MP/d	371.0	424.0	457.0	400.0	472.0	489.0	433.0
Nutrients available for growth[f]							
Energy, Mcal ME/d	5.3	4.3	4.7	5.5	5.2	4.0	0.0
Protein, g MP/d	154.0	115.0	118.0	149.0	130.0	102.0	0.0
Pregnancy requirements[g]							
Energy, Mcal ME/d	…	…	0.1	0.4	1.7	2.7	6.1
Protein, g MP/d	…	…	2.0	14.0	52.0	85.0	206.0
Energy allowable gain[h], kg/d	0.49	0.35	0.35	0.45	0.38	0.28	0.00
Protein allowable gain[i], kg/d	0.74	0.61	0.37	0.82	0.76	0.66	0.00
Inputted gain[j], kg/d	0.49	0.35	0.35	0.45	0.38	0.28	0.00
Feed energy balance[k], Mcal ME/d	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Required %	96.0	95.0	97.0	98.0	100.0	100.0	100.0
Feed protein balance[l], g MP/d	63.0	68.0	-8.0	115.0	128.0	136.0	61.0
Required %	112.0	112.0	99.0	120.0	120.0	120.0	109.0

Appendix Table 11.1 (continued)

[a] Length of grazing time that combines different seasons of forage growth such as early rains (E), late rains (L), scarce rains (S) and low rains (N).
[b] Total amount of dry matter intake from grazing forages and, legumes, mulato hay, sugarcane, and sorghum (when these apply).
[c] Energy supplied by the forage diet and commercial concentrates when they are supplemented.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996)
[f] Amount of nutrients available from the diet after covered the maintenance requirements
[g] Nutrients required for gestation. Energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth
[j] Average daily gain adjusted to the energy allowable gain
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value represents a decline in the average growth rate during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).

Appendix Table 11.2 Heifers reared in GGAVATT Tepetzintla herds born in the season of late rains (August 1) receiving improved diets: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty				
	Supplementation			Grazing	
Forage season[a]	S	S	N	E	L
Heifer age	3 to 6	6 to 7	7 to 10	10 to 12	12 to 15
Grazed forage, kg/d	1.7	2.0	2.5	5.8	7.2
Supplement, kg/d	…	…	…	…	…
Legume, kg/d	0.3	0.4	0.6	…	…
Mulato hay, kg/d	0.9	1.2	1.0	…	…
Sugarcane, kg/d	…	…	…	…	…
Sorhum, kg/d	0.4	0.6	0.5	…	…
Total DMI[b], kg/d	3.3	4.2	4.6	5.8	7.2
Total dietary energy[c], Mcal ME/d	7.3	8.9	9.8	12.4	14.6
Total dietary protein[d], g MP/d	290.0	351.0	377.0	445.0	551.0
Initial BW, kg	95	143	159	207	239
Mean BW, kg	119	151	183	223	263
Final BW, kg	143	159	207	239	287
Maintenance requirements[e]					
Energy, Mcal ME/d	4.3	5.9	621	8.2	9.6
Protein, g MP/d	163.0	194.0	226.0	268.0	341.0
Growth requirements[f]					
Energy, Mcal ME/d	2.4	3.0	3.5	4.1	5.0
Protein, g MP/d	153.0	156.0	153.0	155.0	156.0
Pregnancy requirements[g]					
Energy, Mcal ME/d	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…
Energy allowable gain[h], kg/d	0.61	0.51	0.51	0.50	0.50
Protein allowable gain[i], kg/d	0.50	0.51	0.50	0.58	0.68
Inputted gain[j], kg/d	0.50	0.51	0.50	0.50	0.50
Feed energy balance[k], Mcal ME/d	0.6	0.0	0.1	0.1	0.0
Required %	97.0	91.0	92.0	91.0	92.0
Feed protein balance[l], g MP/d	-41.0	-16.0	-18.0	-4.0	27.0
Required %	88.0	96.0	95.0	99.0	105.0

Appendix Table 11.2 (Continued)

Item	Postpuberty		Gestation (trimester)				
	Grazing		1		2	3	
Forage season[a]	S	N	N	E	L	S	S
Heifer age	15 to 19	19 to 21	21 to 22	22 to 24	24 to 27	27 to 29	29 to 30
Grazed forage, kg/d	8.1	6.1	6.3	8.6	10.0	10.6	7.7
Supplement, kg/d	…	…	…	…	…	…	...
Legume, kg/d	…	0.6	0.7	…	…	…	…
Mulato hay, kg/d	…	…	…	…	…	…	…
Sugarcane, kg/d	…	2.0	2.1	…	…	…	…
Sorhum, kg/d	…	…	…	…	…	…	1.9
Total DMI[b], kg/d	8.1	8.7	9.1	8.6	10.0	10.6	9.6
Total dietary energy[c], Mcal ME/d	15.9	17.0	17.6	18.3	20.1	21.7	21.8
Total dietary protein[d], g MP/d	593.0	552.0	573.0	666.0	766.0	805.0	797.0
Initial BW, kg	287	332	354	365	395	436	449
Mean BW, kg	310	343	360	380	416	443	449
Final BW, kg	332	354	365	395	436	449	449
Maintenance requirements[e]							
Energy, Mcal ME/d	11.8	12.5	13.0	12.5	13.6	16.0	15.6
Protein, g MP/d	404.0	438.0	453.0	390.0	464.0	523.0	454.0
Growth requirements[f]							
Energy, Mcal ME/d	4.1	4.4	4.7	5.7	5.9	3.0	0.0
Protein, g MP/d	114.0	114.0	117.0	155.0	144.0	76.0	0.0
Pregnancy requirements[g]							
Energy, Mcal ME/d	…	…	0.0	0.1	0.6	2.7	6.1
Protein, g MP/d	…	…	1.0	3.0	19.0	85.0	206.0
Energy allowable gain[h], kg/d	0.35	0.35	0.35	0.47	0.43	0.20	0.00
Protein allowable gain[i], kg/d	0.59	0.35	0.35	0.83	0.85	0.39	0.00
Inputted gain[j], kg/d	0.35	0.35	0.35	0.47	0.43	0.20	0.00
Feed energy balance[k], Mcal ME/d	0.0	0.1	0.0	0.0	0.1	0.0	0.1
Required %	100.0	95.0	95.0	97.0	97.0	100.0	100.0
Feed protein balance[l], g MP/d	75.0	-22.0	-19.0	103.0	124.0	121.0	137.5
Required %	114.0	96.0	97.0	118.0	119.0	118.0	121.0

Appendix Table 11.2 (Continued)

[a] Length of grazing time that combines different seasons of forage growth such as early rains (E), late rains (L), scarce rains (S) and low rains (N).
[b] Total amount of dry matter intake from grazing forages and, legumes, mulato hay, sugarcane, and sorghum (when these apply).
[c] Energy supplied by the forage diet and commercial concentrates when they are supplemented.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996)
[f] Amount of nutrients available from the diet after covered the maintenance requirements
[g] Nutrients required for gestation. Energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth
[j] Average daily gain adjusted to the energy allowable gain
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value represents a decline in the average growth rate during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).

Appendix Table 11.3 Heifers reared in GGAVATT Tepetzintla herds born in the season of scarce rain (November 1) receiving improved diets: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty						
	Supplementation					Grazing	
Forage season[a]	S	N	N	E	L	L	S
Heifer age	3 to 4	4 to 6	6 to 7	7 to 9	9 to 10	10 to 12	12 to 15
Forage DMI, kg/d	1.4	1.4	1.8	3.0	3.8	6.5	7.2
Supplement, kg/d	…	…	…	…	…	…	…
Legume, kg/d	0.4	0.5	0.5	0.4	0.3	…	…
Mulato hay, kg/d	0.9	1.1	1.2	0.4	0.5	…	…
Sugarcane, kg/d	…	…	…	…	…	…	…
Sorghum, kg/d	0.4	0.5	0.5	0.3	0.4	…	…
Total DMI[b], kg/d	3.1	3.5	4.0	4.1	5.0	6.5	7.2
Total dietary energy[c], Mcal ME/d	6.8	7.7	8.7	9.3	10.7	13.1	14.1
Total dietary protein[d], g MP/d	267	302	338	355	415	493	506
Initial BW, kg	95	111	143	159	193	210	243
Mean BW, kg	103	127	151	176	202	227	262
Final BW, kg	111	143	159	193	210	243	280
Maintenance requirements[e]							
Energy, Mcal ME/d	3.9	4.6	5.3	5.8	6.7	8.5	10.2
Protein, g MP/d	148	170	196	192	235	308	359
Growth requirements[f]							
Energy, Mcal ME/d	2.2	2.6	3.0	3.3	4.1	4.7	3.9
Protein, g MP/d	156	154	156	163	166	160	122
Pregnancy requirements[g]							
Energy, Mcal ME/d	…	…	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…	…	…
Energy allowable gain[h], kg/d	0.66	0.59	0.56	0.54	0.54	0.52	0.39
Protein allowable gain[i], kg/d	0.51	0.50	0.51	0.54	0.59	0.60	0.46
Inputted gain[j], kg/d	0.51	0.50	0.51	0.54	0.54	0.52	0.39
Feed energy balance[k], Mcal ME/d	0.7	0.5	0.4	0.1	0.0	0.0	0.0
Required %	101	96	94	101	100	91	92
Feed protein balance[l], g MP/d	-49	-37.0	-30	0	14	-1	-1
Required %	85	89	92	100	104	100	100

Appendix Table 11.3 (Continued)

Item	Postpuberty			Gestation (trimester)				
	Grazing			1	2		3	
Forage season[a]	S	N	E	L	S	S	N	N
Heifer age	15 to 16	16 to 19	19 to 21	21 to 24	24 to 27	27 to 28	28 to 29	29 to 30
Forage DMI, kg/d	7.7	5.8	8.0	9.5	10.0	10.5	6.6	6.9
Supplement, kg/d	…	…	…	…	…	…	…	…
Legume, kg/d	…	0.7	…	…	…	…	0.9	…
Mulato hay, kg/d	…	…	…	…	…	…	…	…
Sugarcane, kg/d	…	1.6	…	…	…	…	2.6	…
Sorghum, kg/d	…	…	…	…	…	…	…	3.3
Total DMI[b], kg/d	7.7	8.1	8.0	9.5	10.0	10.5	10.1	10.2
Total dietary energy[c], Mcal ME/d	15.1	15.8	17.0	19.2	19.6	20.6	20.0	21.1
Total dietary protein[d], g MP/d	543	531	617	729	712	749	653	736
Initial BW, kg	280	292	327	358	403	433	439	445
Mean BW, kg	286	310	343	381	418	436	442	445
Final BW, kg	292	327	358	403	433	439	445	445
Maintenance requirements[e]								
Energy, Mcal ME/d	11.1	11.4	11.6	12.9	14.7	15.8	15.2	14.9
Protein, g MP/d	383	405	364	444	493	517	495	478
Growth requirements[f]								
Energy, Mcal ME/d	4.0	4.3	5.4	6.1	4.4	2.7	1.2	0.0
Protein, g MP/d	117	118	157	153	108	71	37	0.0
Pregnancy requirements[g]								
Energy, Mcal ME/d	…	…	…	0.1	0.6	2.0	3.5	6.1
Protein, g MP/d	…	…	…	2	19	64	112	206
Energy allowable gain[h], kg/d	0.37	0.37	0.49	0.46	0.31	0.20	0.09	0.00
Protein allowable gain[i], kg/d	0.51	0.39	0.78	0.86	0.58	0.48	0.13	0.00
Inputted gain[j], kg/d	0.37	0.37	0.49	0.46	0.31	0.20	0.09	0.00
Feed energy balance[k], Mcal ME/d	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Required %	96	94	100	96	97	101	100	100
Feed protein balance[l], g MP/d	28	-14	96	108	76	97	10	52
Required %	105	97	119	117	112	115	102	108

Appendix Table 11.3 (Continued)

[a] Length of grazing time that combines different seasons of forage growth such as early rains (E), late rains (L), scarce rains (S) and low rains (N).
[b] Total amount of dry matter intake from grazing forages and, legumes, Mulato hay, sugarcane, and sorghum (when these apply).
[c] Energy supplied by the forage diet and commercial concentrates when they are supplemented.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996)
[f] Amount of nutrients available from the diet after covered the maintenance requirements
[g] Nutrients required for gestation. Energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth
[j] Average daily gain adjusted to the energy allowable gain
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value represents a decline in the average growth rate during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth)

Appendix Table 11.4 Heifers reared in GGAVATT Tepetzintla herds born in the season of low rain (March 1) receiving improved diets: expected body weights, average daily gains, body weight gains allowed by dietary metabolizable energy (ME) and metabolizable protein (MP), energy requirements (maintenance, growth and pregnancy) and supplies, and feed energy and protein balances throughout the physiological stages of development.

Item	Prepuberty						
	Supplementation				Grazing		
Forage season[a]	E	L	L	S	S	N	E
Heifer age	3 to 5	5 to 6	6 to 8	8 to 10	10 to 12	12 to 15	15 to 16
Forage DMI, kg/d	1.7	2.6	3.2	2.5	6.3	4.8	6.7
Supplement, kg/d	…	…	…	...	…	…	…
Legume, kg/d	0.3	0.3	0.3	0.4	…	0.6	…
Mulato hay, kg/d	0.6	0.5	0.5	1.4			
Sugarcane, kg/d	…	…	…	…	…	1.5	…
Sorghum, kg/d	0.4	0.4	0.2	0.5	…	…	…
Total DMI[b], kg/d	3.0	3.8	4.2	4.8	6.3	6.9	6.7
Total dietary energy[c], Mcal ME/d	6.7	8.1	8.9	10.4	12.4	13.5	14.3
Total dietary protein[d], g MP/d	264.0	316.0	343.0	409.0	459.0	448.0	519.0
Initial BW, kg	95	127	143	175	207	232	266
Mean BW, kg	103	127	151	176	202	227	262
Final BW, kg	127	143	175	207	232	266	282
Maintenance requirements[e]							
Energy, Mcal ME/d	401	4.8	5.5	6.9	8.9	9.5	9.6
Protein, g MP/d	138.0	177.0	199.0	228.0	318.0	348.0	309.0
Growth requirements[f]							
Energy, Mcal ME/d	2.2	2.8	3.1	3.5	3.5	3.5	4.7
Protein, g MP/d	154.0	158.0	154.0	154.0	122.0	112.0	155.0
Pregnancy requirements[g]							
Energy, Mcal ME/d	…	…	…	…	…	…	…
Protein, g MP/d	…	…	…	…	…	…	…
Energy allowable gain[h], kg/d	0.61	0.52	0.54	0.50	0.39	0.39	0.50
Protein allowable gain[i], kg/d	0.50	0.58	0.50	0.59	0.45	0.35	0.68
Inputted gain[j], kg/d	0.50	0.52	0.50	0.50	0.39	0.35	0.50
Feed energy balance[k], Mcal ME/d	0.5	0.5	0.3	0.0	0.0	0.5	0.1
Required %	97.0	95.0	93.0	90.0	91.0	95.0	93.0
Feed protein balance[l], g MP/d	-41.0	-35.0	-27.0	6.0	-6.0	-36.0	31.0
Required %	87.0	90.0	93.0	101.0	99.0	92.0	106.0

Appendix Table 11.4 (Continued)

Item	Postpuberty			Gestation (trimester)			
	Grazing			1	2	3	
Forage season[a]	E	L	S	S	N	E	L
Heifer age	16 to 17	17 to 20	20 to 21	21 to 24	24 to 27	27 to 29	29 to 30
Forage DMI, kg/d	7.0	8.4	8.9	9.3	7.0	9.3	7.4
Supplement, kg/d	…	…	…	…	…	…	…
Legume, kg/d	…	…	…	…	0.7	…	…
Mulato hay, kg/d							
Sugarcane, kg/d	…	…	…	…	1.9	…	…
Sorghum, kg/d	…	…	…	…	…	…	2.1
Total DMI[b], kg/d	7.0	8.4	8.9	9.3	9.6	9.3	9.5
Total dietary energy[c], Mcal ME/d	15.0	17.0	17.5	18.2	18.6	19.9	20.4
Total dietary protein[d], g MP/d	542.0	643.0	656.0	683.0	617.0	726.0	773.0
Initial BW, kg	282	298	345	356	388	417	434
Mean BW, kg	286	310	343	381	418	436	437
Final BW, kg	298	345	356	388	417	434	440
Maintenance requirements[e]							
Energy, Mcal ME/d	10.1	11.3	13.2	13.7	13.8	13.8	12.1
Protein, g MP/d	322.0	394.0	444.0	461.0	482.0	421.0	425.0
Growth requirements[f]							
Energy, Mcal ME/d	4.9	5.7	4.3	4.4	4.2	3.3	2.3
Protein, g MP/d	156.0	156.0	111.0	112.0	103.0	95.0	71.0
Pregnancy requirements[g]							
Energy, Mcal ME/d	…	…	…	0.1	0.6	2.7	6.1
Protein, g MP/d	…	…	…	2.0	19.0	85.0	206.0
Energy allowable gain[h], kg/d	0.50	0.49	0.34	0.33	0.30	0.27	0.19
Protein allowable gain[i], kg/d	0.70	0.78	0.65	0.65	0.33	0.63	0.39
Inputted gain[j], kg/d	0.50	0.49	0.34	0.33	0.30	0.27	0.19
Feed energy balance[k], Mcal ME/d	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Required %	94.0	100.0	95.0	95.0	95.0	97.0	100.0
Feed protein balance[l], g MP/d	44.0	93.0	77.0	86.0	-10.0	106.0	72.0
Required %	109.0	117.0	113.0	114.0	98.0	117.0	110.0

Appendix Table 11.4 (Continued)

[a] Length of grazing time that combines different seasons of forage growth such as early rains (E), late rains (L), scarce rains (S) and low rains (N).
[b] Total amount of dry matter intake from grazing forages and, legumes, mulato hay, sugarcane, and sorghum (when these apply).
[c] Energy supplied by the forage diet and commercial concentrates when they are supplemented.
[d] Total protein supply in the diet by the forage grazed and commercial concentrates supplemented.
[e] Amount of feed energy that results in no net loss or gain of energy from the tissues of the animal body (NRC, 1996)
[f] Amount of nutrients available from the diet after covered the maintenance requirements
[g] Nutrients required for gestation. Energy requirements for gestation during the last 100 days of pregnancy are estimated in the model using the equations of Bell et al. (1995).
[h] Amount of body weight gain estimated by the CNCPS based on metabolizable energy available for growth
[I] Amount of body weight gain estimated by the CNCPS based on metabolizable protein available for growth
[j] Average daily gain adjusted to the energy allowable gain
[k] Feed energy balance = energy intake (feed) minus total energy requirements for maintenance, growth (if allowed) and pregnancy. Generally, a negative value during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth).
[l] Feed protein balance = protein intake (feed) minus total protein requirements for maintenance, growth (if allowed) and pregnancy. A negative value represents a decline in the average growth rate during a stage of growth represents the expected amount of ME supplied from catabolized tissues to support basal functions or pregnancy. A positive energy balance signifies extra energy for tissue accretion (growth)

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